# International Prosthodontic Workshop

# International Prosthodontic Workshop

## on Complete Denture Occlusion

*June 12–15, 1972*

**The University of Michigan**
*School of Dentistry*
*Ann Arbor, Michigan*

*co-editors*

Brien R. Lang

Charles C. Kelsey

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# Foreword

Throughout the years, widely divergent theories on complete denture occlusion have been advanced and practiced. Since the 1920's, many variations of occlusal forms for denture teeth have been designed and made available to the profession. Unfortunately, most efforts to improve the forms of posterior denture teeth were based on admirable goals but inadequate scientific experimentation. Various tooth forms and principles of articulation have been advocated which were based on empirical theories and subjective evidence from clinical practice.

During the past twenty years, sound scientific research in the field of complete denture occlusion has been undertaken and reported. It has been uncertain as to how the results of such research has been applied to the clinical practice of complete denture service.

It was apparent that a meeting of teachers, researchers, and clinicians was needed to assess the current knowledge of complete denture occlusion. A "workshop" seemed to be the best method with which to study this subject. The International Prosthodontic Workshop on Complete Denture Occlusion was organized for the main purpose of appraising the current knowledge of occlusion as related to complete denture prosthodontics.

The objectives of the Workshop were to:

1. Appraise the current knowledge in the field of complete denture occlusion
2. Exchange ideas relative to trends in research and clinical practice as related to complete denture occlusion
3. Focus attention on the primary objectives for future research in complete denture occlusion
4. Provide a publication which could serve as a basis for the teaching of complete denture occlusion
5. Improve the treatment rendered to patients requiring complete denture service with the emphasis on preservation of the remaining oral structures

# Acknowledgments

We wish to acknowledge the contributions of the members of the Organizational Committee, Doctors Dewey H. Bell, Jr., Charles L. Bolender, John B. Heyde, and A. Albert Yurkstas, Jr., for their assistance in the planning stages of the Workshop and for their continued support throughout the activities of the meeting.

We also express our gratitude to Doctor Floyd D. Ostrander for his skillful leadership as parlimentarian for the General Assembly held during the last day of the Workshop.

Doctor Sigurd P. Ramfjord gave freely of his time in assisting the organizers of the Workshop from the initial planning to the completion of this publication. His valuable guidance is greatly appreciated.

We also acknowledge gratefully the efforts of Miss Susan I. Seger, Head Dental Librarian, The University of Michigan's School of Dentistry Library, Miss Ruth E. Cressman, Assistant Librarian, and library assistants, Mrs. Jerri White and Miss Barbara A. Gruschow, for their work in verifying the accuracy of over 1300 references cited in this publication.

Many people were involved in the preparation of materials made available for each contributor prior to the Workshop, secretarial work during the meeting, and in the preparation of the the proceedings for publication. We are especially grateful to Mrs. Helen Kassem and her staff, Mrs. Mari Anne Gillis, and Mrs. Cara Hurst for their efficient secretarial efforts which helped make the Workshop a success. We also wish to acknowledge the patient manner in which Mrs. Deborah Freeman assisted in editing the manuscript and for the many hours spent in proofreading the materials for this book.

*Brien R. Lang*
*Charles C. Kelsey*
*Co-Editors*

# Organization of The Workshop

The Workshop was held in Ann Arbor, Michigan, from June 12–15, 1972, and was supported by The University of Michigan, School of Dentistry, the Educational and Research Foundation of Prosthodontics, Dentsply International Incorporated, and the American Fund for Dental Education. The Organizational Committee was made up of Doctors Bell, Bolender, Heyde, Kelsey, Lang, and Yurkstas with Doctors Kelsey and Lang serving as Co-Chairmen.

There were eighty-nine invited participants from the United States and foreign countries. Expenses of the contributors were paid for with Workshop funds.

The Workshop was organized into seven working sections.

1. Alveolar Bone
2. Physiology of Jaw Movements
3. Articulators and Articulation
4. Occlusal Patterns and Tooth Arrangements
5. Dental Materials as Related to Complete Denture Occlusion
6. Post-Insertion Changes in Relation to Complete Denture Occlusion
7. Human Factors in Relation to Complete Denture Occlusion

## FACULTY OF THE WORKSHOP

Three persons were selected to serve as faculty members for each of the seven Sections. The faculty consisted of:

**CHAIRMAN:** The Chairmen were given full responsibility to run their Sections as they felt would best achieve the objectives of the Workshop. It was the responsibility of each chairman to arrive at a consensus of opinion of his Section members as they evaluated a number of problems related to the Section's topics rather than taking a vote to establish an official position of the Workshop. Each chairman was responsible for submitting a written report to a combined meeting (General Assembly) of all Sections on the last day of the Workshop. The Section reports were read by the chairmen at the General Assembly. The qualifications of the Section chairmen were that they be authorities in the subject area, and have the ability to remain objective as they led the Section members in their deliberations.

**REVIEWER:** The reviewer, or reviewers, were authorities on the topic of their Section. Their responsibilities were to prepare a literature review well in advance of the Workshop.

**SECRETARY:** The secretary was responsible for recording the proceedings of the Section and for preparing the final report for reading at the General Assembly.

The faculty for the seven Sections were:

1. Alveolar Bone

   Chairman: *Douglas A. Atwood, Boston, Massachusetts, USA*
   Reviewer: *Donald H. Enlow, Ann Arbor, Michigan, USA*
   Secretary: *Davis Henderson, Gainesville, Florida, USA*

2. Physiology of Jaw Movements

   Chairman: *Arthur T. Storey, Toronto, Ontario, Canada*
   Reviewer: *Hans Graf, Zurich, Switzerland*
   Secretary: *Parker E. Mahan, Gainesville, Florida, USA*

3. Articulators and Articulation

   Chairman: *Allen A. Brewer, Rochester, New York, USA*
   Reviewers: *Frank V. Celenza, Manhasset, New York, USA*
   *William E. Kotowicz, Ann Arbor, Michigan, USA*
   *Alfred H. Geering, Ann Arbor, Michigan, USA*
   *Heinz O. Beck, Houston, Texas, USA*
   Secretary: *James E. House, Indianapolis, Indiana, USA*

4. Occlusal Patterns and Tooth Arrangements

   Chairman: *Charles M. Moore, Teaneck, New Jersey, USA*
   Reviewer: *Krishan K. Kapur, Boston, Massachusetts, USA*
   Secretary: *Dale E. Smith, Seattle, Washington, USA*

5. Dental Materials as Related to Complete Denture Occlusion

   Chairman: *Robert G. Craig, Ann Arbor, Michigan, USA*
   Reviewers: *Robert G. Craig, Ann Arbor, Michigan, USA*
   *M. Kamal El-Ebrashi, Maadi, Cairo, Egypt*
   Secretary: *William R. Laney, Rochester, Minnesota, USA*

6. Post-Insertion Changes as Related to Complete Denture Occlusion

   Chairman: *Robert M. Morrow, USAF, Honolulu, Hawaii, USA*
   Reviewers: *Robert M. Morrow, USAF, Honolulu, Hawaii, USA*
   *Antje Tallgren, Copenhagen, Denmark*
   *James T. Jackson, Washington, D.C., USA*
   Secretary: *Robert B. Lytle, Washington, D.C., USA*

7. Human Factors as Related to Complete Denture Occlusion

   Chairman: *Alex Koper, Los Angeles, California, USA*
   Reviewer: *Charles C. Swoope, Seattle, Washington, USA*
   Secretary: *Marvin W. Weckstein, Southfield, Michigan, USA*

## PREPARATION PRIOR TO THE WORKSHOP

A comprehensive literature review was prepared for each Section by an acknowledged authority on the subject. The reviews represented the current published knowledge concerning the subject as it related to complete denture occlusion. Mimeographed copies of the reviews were distributed to all of the contributors prior to the Workshop. In addition to the literature reviews, each contributor received a list of suggested "problems" within the scope of his study Section. The responsibilities of each contributor prior to the Workshop were:

1. To study his or her Section's literature review in preparation for discussion during the Workshop, and
2. To prepare to discuss their Section's "problems" relying on their familiarity with the literature review, and their personal research.

## FORMAT OF THE WORKSHOP

Each of the seven study Sections worked separately for the first three days of the meeting. It was the responsibility of each Section to arrive at a consensus of opinion of the group as they evaluated a number of problems within the scope of their subject area. Each Section dealt with three main types of problems:

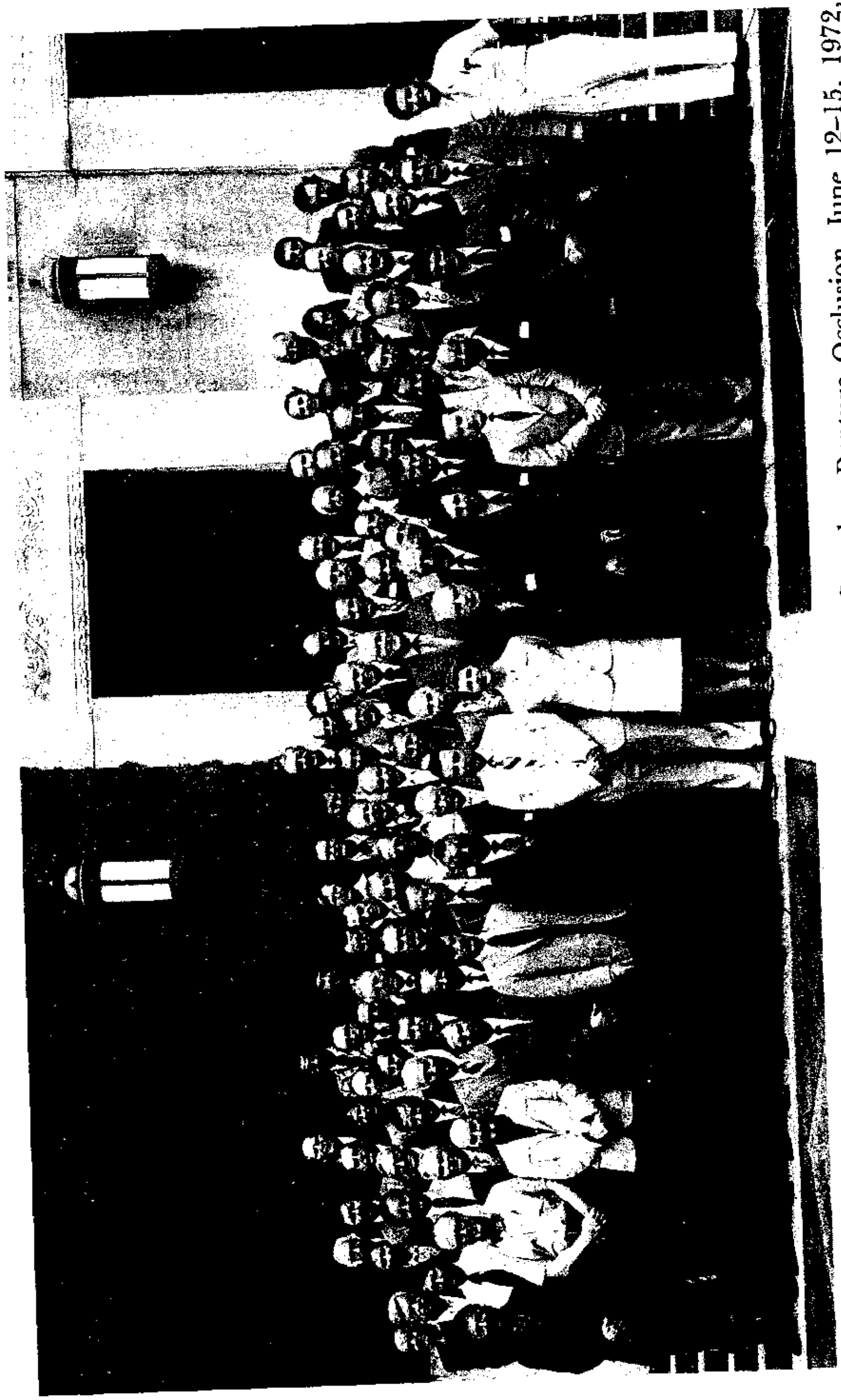
**a.** *Problems of facts:* To determine if alleged facts are scientifically well supported.

**b.** *Problems of belief:* This applies where factual answers are not available but there is need for a working theory or hypothesis.

c. *Problems of future policy:* What should be done to find factual answers where we now are struggling with problems of belief?"*

On the fourth day of the Workshop, the faculty and contributors of the seven study Sections met in the General Assembly. The General Assembly (plenum session) was conducted by Dr. Floyd D. Ostrander, Professor Emeritus of Dentistry at The University of Michigan and past president of the American Dental Association. Following the reading of each report by the Section chairmen, Dr. Ostrander requested that a motion, properly seconded, be made "to accept the report as read with dissenting comments recorded." A given period of time was allotted following each reading for any member of the Workshop to comment on the report.

*Ramfjord, S. P., Kerr, D. A., and Ash, M. M.: World Workshop in Periodontics (1966). The University of Michigan, Ann Arbor.



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# Welcoming Address

*WILLIAM R. MANN*

Members of the Workshop who are from outside the city of Ann Arbor, it gives me great pleasure to welcome you to Ann Arbor, to the campus of The University of Michigan, and to the Horace H. Rackham School of Graduate Studies. The School of Dentistry and the W. K. Kellogg Foundation Institute have had the pleasure and good fortune to conduct quite a series of workshops over the past twenty or twenty-five years, and most of them have made a significant contribution to dentistry and to dental education. I am sure that I do not remember all of the workshops we have had, but I know that we had one in dental caries, two in periodontics, one in orthodontics, one in the teaching of endodontics, one in dental practice administration, and one in the use of auxiliary personnel. I know that some of you have been here for some of these workshops and I hope you have fine memories of them.

I first heard about the need for a prosthodontic workshop about fifteen years ago when Dr. Richard Kingery used to talk to me about it, and I suppose it is from those conversations that Dr. Kingery had with various people that the seed was sown which led to this event. Whenever you have a meeting of this type it really comes about through a combination of several fortunate circumstances. In this instance two people were ready to go to work and devote time and energy to organizing the Workshop and to seek the financial assistance to conduct such an activity. Doctors Brien Lang and Charles Kelsey have devoted a tremendous amount of effort to make this Workshop a reality.

There has to be a source of money for a workshop, and we were very fortunate to secure gifts from three different groups, two quite sizeable gifts from the Educational and Research Foundation of Prosthodontics and Dentsply International Incorporated and a smaller one, but an important one, from the American Fund for Dental Education. This combination of support, and the efforts of a good many of you, have brought us to the beginning of the Workshop. Some of you have already devoted sizeable amounts of time and effort to preparing the literature reviews for the work of this week.

I believe you probably understand what a workshop is, and I hope that you do, because I know that you are all going to work hard before its over. The term workshop, at least in the field of dentistry, has acquired a poor reputation in recent years because anytime someone had a meeting he decided it was going to be a workshop. Consequently, people were just organized into workshop groups, and many of these meetings did not succeed. If you are going to have a workshop and have it be successful, you have to look at it not as a course of instruction, or a conference of some sort, rather it has to be made up of people who are invited to come because of their particular knowledge and their capability of making a contribution to that meeting. That is why each one of you has been selected—because you *do* have that capability. You are not individuals who wanted to come only because you thought you would get something out of it, as so often happens.

We want people to address themselves to the problems which will be raised during the week and then to try to solve them from the most scientific basis possible. When you run out of scientific facts, and when opinion is necessary, you are the people who have well-based opinions, not just casual ones. Because of this possible contribution each of you can make, you have been invited to attend, and we certainly appreciate the fact that you were willing to take the time from your practices or your regular duties as teachers and researchers to be here with us this week. I am sure you are all going to remember this week for the rest of your lives, and I am certain that you will remember it as an enjoyable and productive time.

Thank you again and welcome to Ann Arbor.

*William R. Mann, Dean*
*The University of Michigan*
*School of Dentistry*
*Ann Arbor, Michigan*

# Opening Address

*DANIEL H. GEHL*

It gives me a great deal of pleasure to add my welcome to all of you in attendance at this Workshop on Complete Denture Occlusion. It is a great tribute to our specialty in dentistry that such a group has assembled ready and willing to give of their time and ability to further prosthodontic knowledge. The University of Michigan, School of Dentistry and the organizational committee must be commended for their efforts in gathering together the teachers, clinicians, and researchers assembled here as well as all the materials and manuscripts needed by the contributors to assess the problems related to complete denture occlusion.

Our appreciation must also be expressed to the Educational and Research Foundation of Prosthodontics, Dentsply International Incorporated, and the American Fund for Dental Education for their financial support.

The contributors in attendance this week will have the distinct honor of being participants in the first International Workshop on Complete Denture Occlusion. You are about to make history. This in itself should be of sufficient stimulus for you to contribute the necessary measure of thought, self-expression, and knowledge to guarantee its success.

Our findings and conclusions, if based on scientific evidence and not on personal theories, should have a direct bearing on the future of prosthodontic service and the ultimate improvement in the oral health of our patients.

As we review the literature of the past seventy-five years, we will find many divergent theories and thoughts concerned with complete denture occlusion. As early as 1875, essayists and clinicians were expounding their theories and beliefs. There are many theories and techniques concerning tooth position, jaw relation records, and articulation that were advanced up through the 1920's. During the past fifty years, writers too numerous to mention proposed theories on tooth forms such as flat plane teeth versus anatomic teeth, or teeth with modified occlusual surfaces. Others advocated a variety of occlusal schemes; i.e., balanced occlusions, nonbalanced occlusions, compensating curves, reverse curves, or flat occlusal planes. Claims for specific procedures were based mainly on evidence gained in clinical practice and some research activities. The actual clinical application of research findings have not been fully realized.

The literature contains many articles on articulating devices. There are many types of instruments that have been used by the profession, some quite simple and others extremely sophisticated, which were capable of accepting three-dimensional dynamic registrations. Variance in design and use was often prompted by a definite procedure or function. It might be advisable to study the requirements needed to satisfy complete denture occlusions and apply this knowledge to the design of an instrument capable of fulfilling these needs.

Posterior occlusal forms and tooth arrangements have played a major role in the development of complete denture occlusion. The literature contains many articles describing a variety of designs and arrangements of teeth. This constant search, which has been recorded since 1866 and continues today, emphasizes the fact that the ultimate occlusal form to provide favorable esthetics, retention, stability, maximum masticatory efficiency, and mucosal and bone preservation has not been accomplished.

The physiology of jaw movements, the behavioral pattern of bone under dentures, jaw relation records, tooth forms, and tooth arrangements all need further study. Research based on sound scientific methodology must be encouraged if we wish to reach the goal which is a complete denture occlusion compatible with the preservation of the supporting structures.

Briefly, I have attempted to state the present status of complete denture occlusion. At best, I can only say that it is extremely controversial. There are as many divergent theories as there are authors. Some theories are based on techniques, others on clinical judgment.

The charge to this Workshop is that each of the seven groups will have reviewed the literature for their Section and are now ready to make an honest, unbiased assessment of these theories to see if they are based on scientific evidence instead of unsupported personal theories.

The spirit of informality we hope to achieve during these next few days should allow each contributor to discuss, question, agree, or disagree openly. Your individual expressions will help us to attain our objectives and thus provide recommendations for the future trends in research, education, and clinical practice related to complete denture occlusion.

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## SECTION I

# Alveolar Bone

Review of Literature

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Section Report

General Assembly Discussion

# REVIEW OF LITERATURE

*DONALD H. ENLOW*

Alveolar bone truly represents a conceptual enigma. It is a tissue that is customarily distinguished from "basal" and from alveolar "supporting" bone, and it is believed to have unusual functional and behavioral characteristics. Its geometric boundaries do not lend themselves to any satisfactory anatomical definitions, and its physiological behavior and biological properties are at best difficult to evaluate and explain. Alveolar bone is usually presumed to be a tissue that is secondary in nature and largely dependent upon the teeth it houses. The dentition provides the direct inductive stimulus required for original formation and for the subsequent, long term retention of alveolar bone. Yet, the converse must also be recognized; the teeth themselves depend upon the enclosing alveolar bone and the periodontal membrane. Brodie *(1967)* points out that the alveolar bone is directly responsible for the moving placement of the teeth in relation to the growth of the jaws.

The factor of bone loss must be considered as a critical, primary change that is involved in the ultimate loss of the dentition. From applied as well as theoretical points of view, alveolar bone is certainly one of the most important of the basic oral tissues. It has been estimated that about 25 to 30 million people in the United States are edentulous in one or both jaws *(Nakamoto, 1968; Atwood, 1971; Atwood and Coy, 1971; U.S. Public Health Publication No. 1000-11-7)* and that most wear dentures. Periodontal disease affects nearly 80% of our adults with over half of the population becoming edentulous by the age of 60. The incidence is higher in some other parts of the world *(Israel, 1967)*. Basic causes of alveolar bone loss are poorly understood, and effective methods for controlling alveolar bone before and after tooth loss are presently virtually unknown. The basic underlying physiology of this tissue is not really understood, and such knowledge is thus not available for any rationally based clinical method for direct alveolar remodeling control. The overall situation can be regarded as a major and largely unsolved health problem which Atwood has described as staggering in scope. He emphasizes the special need for new, really effective methods of both prevention and treatment. Many divergent fields and specialties within the dental and other biological sciences have now become involved. With regard to remodeling changes associated with edentulous alveolar ridges, the physical, psychologic, and economic problems for millions of people all over the world represent a major, complex oral "disease" that is chronic, progressive, irreversible, and disabling *(Atwood, 1971)*. The multifactorial origins are little understood, and seriously insufficient knowledge presently exists in the overall etiology of the problem.

## THE PROBLEM OF ALVEOLAR BONE

The behavior of alveolar bone as a tissue is unique. It is particularly labile in nature and is quite sensitive and responsive to a variety of extrinsic and intrinsic stimuli. The basic problem is the question of the *control* of alveolar bone behavior, both in **a.** the normal intrinsic histogenetic process during growth, remodeling, and adjustments to tooth size, position, movements, and loss, and in **b.** clinical control as related to periodontal disease, nutrition, orthodontics, tooth loss, and prosthodontics. The normal control process is not, in any real sense, fully understood. Until this intrinsic control mechanism can be explained, the control process itself cannot be controlled clinically.

Different kinds of growth behavior exist in different parts of a bone. As will be discussed later, a great many bone biologists have presumed that *mechanical* stimulus is the essential basis for virtually *all* of the progressive control influences that govern bone development. That this falls far short of an adequate explanation is now becoming realized *(Enlow, 1968b)*.

To attempt to classify (not explain) variations in the types of bone tissue response during remodeling, Scott *(1955)* describes mandibular bone as "basal," "muscular," and "alveolar" in nature and points out that each has a basically different kind of growth character. Washburn *(1947)* also suggests that three main categories of bone tissue responses can be recognized: **a.** that which does not appear unless muscle attachment is directly involved, **b.** that which is self-differentiating but requires the presence of muscle to remain, and **c.** that which is largely independent of any direct muscle activity but which may involve genetic predisposition in conjunction with a complex variety of other mechanical and developmental factors. Such simple but meaningful taxonomy, however, does not give us the answer we need; i.e., how the control systems involved actually work. This is to be regarded as one of the most basic and important problems in all of bone biology.

Histologically, alveolar bone is not particularly different from other kinds of bone tissue. Like most of the various types of bone, it is a sensitive tissue that responds to a variety of normal and experimental stimuli. Like all tissues, it has definite thresholds for such stimuli, and these are believed to be notably low, particularly in a field of compression. Some threshold response levels can also be quite high in alveolar bone, however, and the basis for this differential behavior is not understood. Alveolar bone, as previously mentioned, appears to be a largely dependent type of tissue which is secondary to the teeth it supports. This concept, however, will likely become modified as more is learned of intrinsic control mechanisms and the nature of bone-tooth-soft tissue interrelationships and feedbacks.

Alveolar bone appears to be fundamentally different from basal bone in stimulus-response characteristics, and a variety of relationships exist that may be associated with this difference. Recent studies suggest that alveolar and basal bone may have separate origins and thereby also have different developmental potential and programming. Freeman and Ten Cate *(1971)* have shown, using autoradiographic techniques, that alveolar bone may be derived from specific cells originating in the dental papilla. Biggerstaff *(1972)* has observed separate, hyaline-like cells in the developing jaw (of the hamster) that apparently give rise directly to the primordial tissues of bony alveolar ridges. Other features that bear upon the structural-functional interrelationships of alveolar bone are discussed below.

## THE MICROSCOPIC STRUCTURE OF ALVEOLAR BONE

The adage that all "bone is bone" is certainly not true. Many different histological varieties of bone exist and each type represents a specific structural adaptation to particular developmental, mechanical, age, and functional relationships.

Alveolar bone is usually described as a mixed combination of "bundle bone" and lamellar bone containing Haversian systems. This is inaccurate and incomplete. It is important to realize that several different basic bone tissue varieties exist and that each has specific functional relationships associated with it. These types are briefly described below. It is noted that none is specifically restricted to the alveolar process associated with teeth, and that all can also occur in other skeletal areas. See Enlow *(1968a)* for a more detailed account.

**BUNDLE BONE.** This is the conventional type most often mentioned in relation to tooth-supporting bone tissue. It is a bone tissue in which massive bundles of parallel collagenous fibers (Sharpey's fibers) of the periodontal membrane have become progressively embedded and buried as the alveolar bony plate grows around them. It is noted that this is "periodontal" bone which is homologous with "periosteal" bone. The periodontal membrane itself is a direct extension of the periosteum, and both *periodontal bone* and *periosteal bone* are to be distinguished from endosteal bone, as described under other types below. Bundle bone always develops in an appositional direction toward the tooth root. It is always associated with the so-called tension side of the socket unless a subsequent reversal occurs that can then result in the resorption of this bundle bone which is then on the "pressure" side.

**LAMELLAR BONE.** This is a generalized type of bone tissue that can occur in conjunction with other histologic types. For example, the underlying bone associated with the bundles of attachment fibers (bundle bone) can be either lamellar or non-lamellar in nature. The lamellar arrangement is a stratification produced by varying matrix fiber orientation in alternate lamellae. This type of bone is characteristically produced during relatively slow periods of continuing bone deposition. It is thus found in slower-growing *localized* areas in conjunction with other bone types that form in other faster growing regions. It is seen at all age levels but is of course particularly widespread in the older skeleton.

**NONLAMELLAR BONE.** The matrix in this bone type is not stratified due to the homogeneous mode of fiber deposition. The osteocytes have a characteristically more random distribution and do not occur in regular, circumferential layers as in lamellar bone. The intercellular matrix has a characteristically more basophilic staining reaction. Nonlamellar bone is formed during periods of relatively rapid accretion and is a feature of the fetal skeleton and the fast-growing child. Rapid remodeling movements of alveolar bone usually involve the formation of this tissue type. It can be of periosteal, periodontal, or endosteal origin.

**FINE-CANCELLOUS BONE.** Frequently associated with nonlamellar bone, this tissue type is also formed during periods of particularly fast bone deposition. During the fetal and early postnatal growth of the skull, virtually the entire maxilla and mandible are composed of fine-cancellous bone, including the "compacta" of the cortex. It is also a common type of bone at any age in those particular regions involving a transient period of rapid bone formation. Fine-cancellous bone, which has somewhat larger vascular spaces than ordinary compact bone but smaller cancelli than the coarse-cancellous type of bone, is always of a nonlamellar type. The spaces, however, can become filled by either lamellar or nonlamellar bone to convert this tissue variety into compact bone. This filling-in process produces "primary osteons," a common and often encountered structure in most species, including man. It is little known, however, since this (and most other) basic bone types are not described in most standard textbooks. Fine-cancellous bone can be of periosteal, periodontal, or endosteal origin.

**COARSE-CANCELLOUS BONE.** This is ordinary "spongy" bone and is characteristically located in medullary spaces. It is always of endosteal origin and by definition is not produced by either the periosteum or periodontal membrane. The cancellous bony fill in the fundus of the alveolar socket following extraction, for example, is produced specifically by the endosteum. The spongy bone of the edentulous ridge, similarly, is also of endosteal origin. Coarse-cancellous bone can be either lamellar or nonlamellar in type depending on its relative rate of formation. It comprises the "supporting bone" surrounding the thin compacta of the alveolar bone proper (the lamina dura as seen in radiographs).

**COMPACTED COARSE-CANCELLOUS BONE.** This is a most important type of bone tissue and represents a significant percentage (about half or more) of the various types of tissues which comprise alveolar bone proper as well as most other bones in the skeleton. Paradoxically, this is a bone tissue that is seldom mentioned in most basic texts.

This tissue type is formed by a direct conversion process from cancellous to compact and from medullary to cortical bone. The cancellous spaces become filled with lamellar bone until the resultant spaces are reduced to ordinary vascular canal dimensions. Compacted cancellous bone is always of endosteal origin and its outer surface, contiguous with the periosteum or periodontium, is usually resorptive in nature. This type of bone is formed when the alveolar cortical plate grows into any region previously occupied by cancellous trabeculae, as on the "pressure" side of the alveolar socket. The convoluted nature of compacted cancellous bone somewhat resembles true secondary osteons (Haversian systems) and have often erroneously been identified as such in the literature. Compacted cancellous bone may be termed "convoluted bone tissue" and represents a significant type that is encountered in almost any routine microscopic section of bone.

**HAVERSIAN BONE.** Although this is the familiar bone type emphasized in basic texts, it is not a significant structural component in many areas of cortical bone. Further, it is not widespread during the postnatal growth period, and many species lack this kind of bone altogether. The secondary osteon should *not* be regarded as an ubiquitous "unit" of structure. Haversian systems are not a prominent feature of alveolar bone, and even during the more advanced age levels when Haversian systems begin to accumulate in some other bones, they can be scarce or entirely absent in the alveolar plates. Osteons are "secondary" because they replace original primary bone during a process of internal cortical reconstruction. This process serves to rebuild areas that have become necrotic and to replace them with a new generation of living bone. Necrosis is a normal process in all bone during aging. Highly vascular types of bone live for longer periods than the less vascular varieties, but the life span of any bone tissue is limited *(Enlow, 1966)*. During the childhood period, the process of growth itself serves to replace older with new bone. After growth ceases, however, remodeling associated with growth no longer provides this continual resorptive, regenerative function. Cortical Haversian reconstruction provides this process of tissue replacement, and secondary osteons thus accumulate for the remainder of life. Mobilization of mineral is also provided by this same process. Haversian systems or their equivalent also function in muscle and tendon attachments on remodeling, resorptive surfaces of a bone *(Enlow, 1963)*.

**VASCULAR AND NONVASCULAR BONE TISSUES.** The density of vascular canals within compact bone is directly proportional to the rate of deposition. Fast bone growth results in highly vascularized bone and very slow growth is associated with poorly vascularized or totally nonvascular types in both periodontal and endosteal varieties of alveolar bone. On the "pressure" side of the teeth, whether or not the cortical alveolar plate is vascular bears directly on the mode of periodontal fiber attachment (see under *soft tissue attachments* below).

Highly vascular bone tissue is more resistant to progressive osteocyte necrosis than the less vascular varieties. As overall skeletal growth slows, the density and distribution of canals decreases and necrocytosis then becomes accelerated. The relative density of canals is also related to the effect of osteoporosis on the bone tissue, a factor of key importance in tooth loss. These considerations are discussed in sections that follow.

**CHONDROID BONE.** It is surprising that one of the most unusual and characteristic types of bone found in the alveolar process has received very little detailed study. Except for brief mention in some texts, only a few studies have recently been concerned with chondroid bone. This bone tissue type is characteristically found as a cap at the apex of a fast-growing alveolar ridge (it is also found at the growing apex of many tendon-attachment tubercles on long bones). The cartilage-like appearance of the densely distributed, large cells and a nonlamellar matrix characterize chondroid bone *(Enlow, 1963, 1968; Gussen, 1968a, 1968b)*. It apparently undergoes direct metaplasia into ordinary nonlamellar bone, thus suggesting that this is one type of bone tissue that can actually undergo a kind of true interstitial growth or remodeling. The physical properties and the nature of its particular adaptive functions are little known.

## THE REMODELING OF BONE

**RESORPTION AND DEPOSITION.** These two growth processes mutually complement each other, and the combination represents the basic mode of skeletal growth and remodeling. The realization that bone undergoes a process of surface resorption during growth was a major conceptual breakthrough in the 18th century. Resorption is of course a normal process and is just as necessary to growth as deposition. In a restricted clinical sense, "resorption" has often been regarded as undesirable. During childhood, however, deposition complemented by resorption provides for growth and also brings about the necessary process of *remodeling*, which is a basic and integral part of growth. Remodeling is also a process that provides many other kinds of skeletal adjustments in a complex variety of circumstances. Osteoporosis, for example, is a type of remodeling, and it has been argued whether or not this is also a "normal" phase of skeletal physiology or a "disease" process *(Garn, et al., 1966; Atkinson, 1969)*. Similarly, reduction and loss of alveolar bone following loss of teeth is actually a normal, adaptive remodeling process. The sharp edges of the protruding alveolar ridges become removed thereby allowing effective gingival coverage and edentulous occlusion. Yet this same regressive remodeling process, which is normal and desirable, can also be defined as a significant and important *disease* process because it can interfere with denture stability.

**EFFECTS OF OSTEOPOROSIS IN DIFFERENT KINDS OF BONE.** In some varities of osteoporosity, the presence or absence and also the relative density of vascular canals in cortical bone, including alveolar bone, directly influences the nature of response to the onset of osteoporosis. Because initial changes in osteoporotic bone loss involve the enlargement of existing vascular canals into fine-cancellous dimensions, the presence of a great many canals in the densely vascular types of bone provides the basis for a great deal of bone loss within the substance of the cortex itself. The overall thickness of the cortex may not be materially affected, but its porosity becomes greatly increased. Resorption on periosteal and endosteal surfaces is thereby not a major factor, at least during the earlier stages.

If the bone tissue type is sparsely vascularized or locally entirely nonvascular, however, the existence of bone surfaces *within* the cortex is much less extensive or completely absent. Bone loss then occurs directly from either or both the periosteal and endosteal surfaces. In contrast to the development of a highly spongy and porous type of cortex, thus, osteoporosis in these bone types becomes associated with a thinning of the whole cortical plate with the plate itself retaining a compact character.

**THREE KINDS OF ALVEOLAR BONE REMODELING.** "Remodeling" is a standard term often used in any discussion dealing with bone, yet many investigators are not aware of the functional basis for the different basic types of remodeling. First, remodeling is a process that serves to change one part of a growing bone into another part and, at the same time, retain the overall shape of a whole bone. Thus, the "old" ramus becomes remodeled into the lengthening corpus as the new ramus continues to grow posteriorly. Former areas of alveolar bone become remodeled into the basal bone of the corpus as the teeth erupt. The maxillary arch becomes sequentially remodeled into the palate as both continue to grow inferiorly. This is "growth remodeling."

Second, the term remodeling is often used by the biochemist and physiologist to describe the general process of feedback involved in mineral homeostasis. Thus, calcium release, trabecular resorption, ion-exchange, and all similar processes provide a remodeling system at the molecular level.

Third, remodeling is used to describe the process of histologic cortical reconstruction. The often-used comment that "bone remodels throughout life" is a valid principle, although many do not realize just what the real nature of this functional process is. It provides a system for the internal replacement of aging bone without disturbing the overall form of the whole bone itself. Thus, dead or dying cortical bone becomes progressively replaced by new (Haversian) bone tissue. It is possible that this process may be a factor in the cause for losses of teeth, as will be discussed later.

**ALVEOLAR BONE AND BIOMECHANICAL FORCES.** Of all the different extrinsic and intrinsic factors that can affect bone, tensions and pressures have been presumed for nearly a century to be *the* factors which most influence and regulate the processes involved. That this presumption may or may not be entirely justified is evaluated briefly in the present report. However, alveolar bone is commonly regarded as a bone tissue type that is particularly sensitive to physical forces, and in which the threshold for compression is especially low. It is generally accepted that alveolar bone is not dependent upon direct genetic coding or any established histologic programming, and that muscle action is not required for its development and maintenance. Tension is usually regarded as the type of stimulus that results in bone deposition, and pressure is believed to be the force that results in bone resorption. See Epker and Frost *(1965–1966)* for a critical evaluation of surface curvatures and the nature of stresses and strains. They show that compression, not tension, can be directly related to bone deposition, and tension can be associated with resorption. Quantitative levels of tension and pressure required under the complex and varied circumstances associated with alveolar bone are not fully known, although the uses of "light" and "heavy" forces and their differential effects are widely discussed *(Moyers and Bauer, 1950; Smith and Storey, 1952; Baxter, 1967; Gianelly, 1968; Utley, 1968)*. For a discussion of the amount of force as it relates to dentures and alveolar resorption, see O'Rourke *(1949)* and Brudevold *(1951)*.

While the nature of actual forces involved is poorly understood, it has long been realized that teeth move actively through the bone of the jaw during overall bone growth and during eruption and "mesial drift." Such tooth movements involve alveolar remodeling by deposition and resorption in specific parts of the alveolar processes according to the particular directions of tooth movement at any given time or in any local area. Bone is added on that surface which faces the localized direction of movement, and bone undergoes resorption from those contralateral surfaces which are oriented away from the localized movement direction *(Enlow, 1968a)*. That such a general process occurs in the bone tissues associated with the periodontal membrane was apparently first recognized by Black *(1880)*. Kingsley *(1880)*, however, suggested that external forces produce a movement of teeth due to the elasticity and physical bending of the alveolar plate. Farrar *(1888)* also recognized bending of the alveolar bony plates as a possible factor but also realized that resorption and deposition occurred at the same time. These early accounts are interesting since some present-day investigators have returned to similar, albeit more sophisticated, explanations (see under piezo effect below; refer also to *Baumrind, 1969*).

Edward H. Angle *(1907)* also recognized that bone is resorbed in advance of a moving tooth and laid down following it. Baumrind *(1969)* reports that until the time of Angle, mechanical forces employed in "tooth regulation" were so extreme that outright fractures of the alveolar process occurred. The "light" force concept in Angle's new school was strongly supported by Oppenheim *(1911–1912)*, who eventually came to believe that "bending" of the bone was not involved at all and that only surface response to pressure and tension produced alveolar remodeling during tooth changes *(1933)*.

The actual histologic changes involved in resorptive and depository alveolar remodeling were described by Sandstedt in 1904. He also introduced the concept of "undermining resorption," a process that is believed by some to occur in the face of strong forces (see later discussion). Brash *(1927)*, in the course of his famous vital dye studies, clearly demonstrated the process of deposition during alveolar growth. He also pointed out that the bone tissue of the alveolar wall undergoes a process of microscopic reconstruction even when the tooth is stationary.

Sicher and Weinmann *(1944)* formalized the principle of drift as a physiological movement of the teeth "throughout the life" of the individual. Although this concept is valid and well documented, it is not generally realized that drift involves a significant extent of vertical movement of teeth as well as mesial or distal shift during the growth period, particularly in the maxilla *(Enlow, 1968a).*

The structural arrangement of alveolar trabeculation and the nature of its variations have been described by Parfitt *(1962).* The spacing of trabeculae in relation to the variable forces of mastication was discussed by MacMillan *(1926),* and Johnson, *et al. (1926)* related the orientation of alveolar trabeculae to specific directions of tooth movement. Herzberg *(1932)* also showed experimentally that bony trabeculae become arranged parallel to the direction of movement. Breitner *(1940)* stated that trabecular orientation was in the direction of orthodontic pull and, also, approximately perpendicular to the long axis of the tooth. However, Stafferi *(1958),* in a roentgenographic study, claimed that each person has his own characteristic, inherited patterns of alveolar trabeculation. Despite localized changes produced by therapy, the overall pattern does not change and any local changes are temporary in nature and the original pattern will return. (Note: this "heredity vs. mechanical force" argument is basic to our present dilemma of alveolar control, as discussed in a following section).

The magnitude of biomechanical force as it relates to the stimulus, rate, and the extent of bony remodeling has, historically, been keenly controversial. In a recent study, Utley *(1968)* concluded that osteogenetic activity and structural dynamics increase in response to the level of forces accompanying experimental tooth movements. Other workers, however, have stated that the actual magnitude of force is irrelevant so long as the distance of any bone-tooth movement does not obliterate periodontal blood vessels *(Stuteville, 1937, 1938).* Should any force on alveolar bone be at a level that does not compress and occlude the vessels (i.e., "light forces"), it is presumed that only *frontal* resorption occurs on the immediate alveolar surface which directly receives the pressure. Conversely, if the periodontal vascularization is totally occluded by "heavy forces," the immediate site of compression cannot thereby respond and *undermining resorption* then takes place. This involves a resorptive advance into surrounding cancellous areas contiguous with the alveolar plate proper. In experiments using dogs, Gianelly *(1969)* demonstrated that a relationship does exist between the patency of localized periodontal vascularization and the occurrence of either frontal or undermining types of resorption. He also relates the previous studies of Stuteville *(1937, 1938)* and Bien *(1966)* and suggests that the vasculature represents a hydraulic system which transmits localized fields of variable compression, according to the state of distention, onto the face of the alveolar plate. Like many present-day investigators, Gianelly mentions the piezo reaction to crystal distortion as a possible means of response to the trigger effect of direct compression on the alveolar bone surface. DeAngelis *(1970),* in his own series of experiments, places importance on the deformation (bending) of alveolar bone by mechanical forces and believes that the thickness of the bony plate is the essential basis for a differential response to the stimulus. A similar concept has also been proposed by Smith and Storey *(1952).* Thus, the thinner alveolar bone plates associated with the anterior teeth have a lower threshold to bending and subsequent resorptive remodeling than the more posterior teeth. DeAngelis also speculates that the piezo effect may account for bone tissue responses to force. He questions that the basis for "undermining" resorption is due to any strong-level force, however, and states that remodeling of the cancellous trabeculae contiguous with the alveolar plate is simply an integral part of the overall process of coordinated bone and tooth movements. That is, the supporting trabeculae drift by deposition and resorption in the same direction of movement as does the alveolar bone proper. The biomechanical stimulus, thus, is not restricted just to that localized surface directly receiving the stress but is passed onto surrounding bone tissues as well. Coordination of all these remodeling changes occurs so that the alveolar plate remodels in conjuction with its surrounding cancellous tissues. DeAngelis regards the physical bending of bone as the probable factor that triggers the piezo effect which in turn stimulates osteoblastic and osteoclastic response.

Baumrind *(1969),* similarly, believes that the bone *must* be actively deformed in order to elicit any significant extent of remodeling reaction. He notes the ease with which alveolar bone can be distorted by experimental forces, and states that the degree of deflection is related directly to the magnitude of the force applied. He does not believe that force-created changes in the periodontal membrane itself, without associated bone deformation, can be the sole factor that serves to elicit bony response. Epker and Frost *(1965–1966)* also maintain that active deformation (strain) is required in order to trigger any remodeling response. They suggest that mechanically increased or decreased surface curvatures are the specific stress or strain changes that activate bone producing and/or resorbing cells.

As previously mentioned, the magnitude of any physical force acting on alveolar bone has been regarded by most investigators as a basic factor. Reitan *(1951)* has stated that continuous forces produce a deposition of osteoid tissue in areas of tension and that this tissue type also occurs in conjunction with resorption at pressure-exposed surfaces. When the forces exceed that tissue's particular intrinsic tolerance level, a pathologic response then results. Reitan *(1957, 1960)* has also noticed the presence of a cell-free osteoid tissue in areas of compression as an initial, transitory reaction, and has stated that this tissue appears to be relatively pressure-resistant. Baxter *(1967)* also calls attention to the seemingly common occurrence of osteoid covering the alveolar surface during remodeling. This tissue, which is an uncalcified osseous matrix, is ordinarily regarded as a normal type of tissue unless it becomes widespread and more or less permanent. In most bone forming areas, it is caused by a temporary calcification lag after the bone matrix has been laid down. Whether or not osteoid has a special function in tooth-bearing bone during alveolar remodeling, perhaps as a pressure-resistor, is an interesting possibility.

While most investigators have concluded that the *amount* of any force is critical to remodeling changes, it has been pointed out by Reitan *(1951)* and by Ackerman and Cohen *(1966)* that *duration* is also directly involved.

The various biomechanical and remodeling relationships described above involve only the periodontal membrane and the immediate bone tissues associated with the alveolar processes. The anatomical, functional and developmental nature of the orofacial complex in general, however, is very much a "house of cards." Alterations in the position, size, or relationships of any one part become passed on from area to area and give rise to a *chain* of responses by many other soft and hard tissues throughout the facial complex. Gingival adjustments, submucosal connective tissue responses, buccal and labial musculature adaptations, blood vessel changes, altered nerve innervations, temporomandibular adjustments, and many other similar consequences all become involved. Thus, remodeling activities associated with teeth and alveolar bone can extend much beyond the alveolar process itself and the associated periodontal membrane.

**SOFT TISSUE ATTACHMENTS TO BONE.** The periodontal "ligament" is a complex, layered, vascular and cellular, dense fibrous membrane that is directly continuous with the periosteum. It is comparable with the periosteum in both structure and modes of activity. Unlike the periosteum, the periodontal membrane also involves fibrous attachments to the cementum of teeth. This special function, however, is carried out in a manner similar to another structural variation of the periosteum (the sutural membrane) which provides bone-to-bone connections. Like any periosteal bone surface throughout the skeleton, the "periodontal" surface of alveolar bone can be either of a *depository* or a *resorptive* type. This requires different periodontal mechanisms with regard to growth relationships and fibrous attachments. Because the retention or the loss of the dental arch and also the remodeling activities of alveolar bone itself all involve direct fibrous anchorage, the mode of periodontal remodeling is of basic importance.

The periodontium *remodels* just as the bone tissue associated with it undergoes continued remodeling changes and adjustments. This membrane is not simply "moved" as a whole, unchanging unit, as the contiguous alveolar plate moves by deposition and resorption. The process of soft tissue remodeling is concerned with cellular repopulation, vascular realignments, maintenance of innervations and, particularly, fibrous reconstruction in order to provide shifts in membrane position and the maintenance of uninterrupted attachments and tooth anchorage.

How can the periodontal membrane sustain continuous attachment onto a *resorptive* face of alveolar bone? The conventional explanation holds that "spot" deposits of new bone are apposed onto recently resorbed surfaces, and that these thin, transitory scales of bone provide waves of temporary anchorage which alternate with periods of resorption here and there throughout the "pressure side" of the socket. Some areas thus give attachment while others undergo resorption. The question is not answered, however, as to how such spot deposits themselves are firmly attached onto a severed, resorbed surface which had previously experienced total membrane and fibrous detachment. This is a basic consideration that is relevant to all circumstances involving alveolar remodeling, including mesial drift, eruption, growth, the remodeling of the mandible and maxilla as a whole, osteoporotic changes, loss of teeth, residual ridge remodeling, and gingival attachments. The same problem exists with regard to periosteal and muscle anchorage to resorptive surfaces of a bone.

Spot deposits are in fact formed on the resorptive surfaces of a remodeling socket, although they may represent a structural result of a somewhat different process. Their functional importance, also is questionable since the attachment is not secure and separation is usually noted in routine histologic sections. Also, the extent of a "spot" deposit is misleading since its actual coverage can extend far beyond the apparently small areas seen in thin sections. Coverage extends well into the adjacent cancellous bone, a feature that is not always recognizable except in serial sections or in thick preparations. Spot deposits usually represent exposed remnants of the process of compaction of cancellous bone, in conjunction with surface resorption, as previously described. This process itself, however, is a mechanism involved in membrane attachment.

At least two functional systems can be identified in fibrous attachments onto regressive alveolar surfaces or any other kind of resorptive bone surface *(Enlow, 1968a)*. Many areas are encountered in which previous periodontal fibrous anchorage is only partially severed and released as a direct consequence of the resorptive removal of that bone in which attachment fibers were formerly embedded. A key feature of the resorptive process is that some fibers that were a part of the ordinary bone matrix do *not* become resorbed. These fibers subsequently become converted from bone matrix fibers, which are already directly continuous with the existing fibers of the PDM, into actual new periodontal fibers upon their release from the bone matrix. This process thereby sustains continuous attachment in these particular areas. Such regions are characterized by bone matrix fibers which have an alignment that coincides with that of the tensile forces present in that region (the collagenous fibers on the pressure side of the socket can be under actual tension; any pressure is *not* transmitted by the fibers themselves). In other areas where fibrous alignment within the bone matrix does not coincide with the direction of fibrous tension in the PDM, total bone matrix resorption then occurs. A comparable process occurs in other bones where periosteal surface resorption takes place at sites of muscle and tendon attachment.

The second mechanism of fibrous anchorage on resorptive alveolar surfaces, which is also seen in other bones at locations where muscle attachments are involved, is that of Haversian remodeling deep to the resorptive surface. In advance of the resorptive front, erosion spaces which are continuous with the resorptive surface become continuously formed and reformed. Within these spaces, secondary bone is laid down, and the entire fibrous matrix of this new bone is directly continuous with the fibers of the PDM. This bone can be in the form of Haversian systems (secondary osteons) if the alveolar cortical plate is broad enough to contain them, or it can simply be a layer of new cortical bone produced by a compaction of pre-existing cancellous spaces. Thus, fibrous attachment of the PDM to the resorptive side of the alveolus is sustained by anchorage *deep* to the resorptive surface itself. As the resorptive front proceeds, such areas themselves become exposed and destroyed, and the process continues in advance of the moving front. Such exposed remnants of secondary bone probably represent much of what has been regarded as so-called spot deposits.

Interestingly, this mechanism of membrane anchorage involves "undermining resorption," as described in earlier paragraphs, although the functional nature is entirely different from that usually associated with this process. Thus, resorptive activity in the supporting cancellous bone adjacent to the alveolar plate proper can be a feature associated with progressive membrane reattachment as well as cancellous drift (as suggested by DeAngelis) and heavy forces (according to conventional theory).

As the tooth erupts, drifts, becomes relocated in relation to the growing jaw, or as teeth are lost and as the alveolar ridges undergo regression, the periodontal membrane and the periosteum themselves remodel in conjunction with these changes. This requires sequential conversions of precollagenous to collagenous fiber types, and the converse, as these fibers adapt to the moving bone surfaces. These changes are described in detail by Enlow *(1968a)*.

## A SURVEY OF POSSIBLE CONTROL FACTORS IN ALVEOLAR REMODELING

It is apparent that the most basic and important of all our current, unresolved problems in skeletal physiology is the question of the *local control mechanism*. The history of advances in bone biology through many centuries has involved a succession of conceptual roadblocks that held up meaningful progress until notable breakthroughs were made and progress could then continue until the next major block was encountered *(Enlow, 1963)*. Breakthroughs, historically, have followed the introduction of new research tools (such as the microscope, vital staining, and radiography), new basic concepts (such as the cell doctrine and the first discovery of the process of "resorption" in bone), special men (John Hunter), or the accumulation of many separate pieces of information to form a single grand principle (Wolff's Law). The great block that we have encountered in our own time is the meaningful explanation of the local control mechanism. This may well prove to be the most critical and formidable conceptual obstacle of all time. The breakthrough, when and however it comes, will mark the beginning of a new era.

Traditionally, most investigators dealing with bone tissue have accepted the concept that biomechanical forces represent the sole, or at least the principal, factor that regulates the course of bone remodeling throughout childhood and adult life. The rationale that underlies this idea is, on the surface at least, quite rational and seemingly well founded. Using the concept of tension-deposition and pressure-resorption, one may resonably explain virtually the whole of skeletal growth and physiology from fetus to old age *if* one "believes" in the basic premises required and does not question the modes of operation involved. Because of the reasonableness and attractiveness of the overall concept, biomechanical explanations in one form or another have served as the keystone for most of our past and present explanations of remodeling control. These concepts state, essentially, that bone is entirely dependent upon stresses for continued differentiation response, and the various kinds of adaptations required during life. When stress is applied to a bone, the osteoblasts and/or osteoclasts are stimulated by this stress to function, and remodeling takes place until subsequent growth and adjustments neutralize the imbalances of forces and bring them to equilibrium. At this time, growth or remodeling ceases until such future time that any force imbalances are again introduced and force equilibrium once again becomes disturbed. Tension has usually been accepted as the trigger for bone deposition, and pressure has been believed to bring about resorption. Some recent workers however, such as Frost *(1963)*, and Epker and Frost *(1965–1966)*, have produced much conflicting evidence in this regard. Tension, however, has conventionally been presumed to stimulate osteoblasts to produce new bone so as to adapt the bone to this stress, and that bone's definitive shape is thereby eventually produced with all of its tuberosities, crests, enlarged epiphyses, etc. located at the specific sites of the mechanical pull. When all muscle stress and other forces become balanced, further remodeling ceases because the immediate stimulus has been removed. If the stress itself is taken away, that bone tissue adapted specially to the stress then undergoes resorptive regression by the stimulus of osteoclastic activity in that particular area. These various premises have been "tested" by the cutting of muscles, application of different artificial forces, and many other similar experiments designed to show a skeletal reaction. Because the bone always responds in some manner, it is usually concluded that "force" is therefore *the* essential agent that is responsible for the basis of all remodeling control.

The question must now be asked, however, as to whether or not factors that can affect or change a tissue necessarily must *also* be the *same* factors that carry out the direct control of its growth, differentiation, and physiological behavior. If a soft tissue biologist were to experimentally create simple structural changes in muscle, ordinary connective tissue, or epithelia by applying unusual ectopic stresses to these soft tissues, he would certainly not conclude that stress is therefore the sole primary factor of tissue control. Yet this, in effect, is just what the skeletal biologist has done since the many *other* factors that can be directly involved are not usually taken into account. A general classification scheme is proposed below that will be used to categorize the many, varied factors that can contribute to control in order to place each in perspective relative to the rest.

1. A given factor is *the* means of primary tissue control for growth, remodeling, repair, regeneration, etc. No other factors are directly required.
2. A given factor functions as a *trigger* that stimulates the *real* agent or agents of control, whatever these may be. This factor is thus one of a *chain* of factors.
3. A given factor is a title for some biologic event or process but does not explain the means by which the direct control of this process is regulated. That is, this is a *label* and is in effect a synonym for the "control process" itself without accounting for the actual mode of its operation.
4. A given factor is required to be present in order to *support* the primary control mechanism but is itself of a secondary or subordinate nature.

Outlined below is a survey of a number of possible control factors and a brief evaluation of each. It is pointed out that overall control requires variable combinations of such factors in the many different circumstances that characterize the skeletal environment.

**BIOMECHANICAL FORCES.** Pressures and tensions *must* be involved in growth and functional remodeling control in some manner, either as an actual control agent or as a factor that must at least be accommodated by other control systems. Mechanical forces might be directly involved in some circumstances but represent only a secondary factor in others. In any event, however, a one-to-one correlation between tension and deposition (or between pressure and resorption) does not always exist. That is, depository and resorptive remodeling fields and the boundaries for the attachment of muscles and other stress-causing tissues often do *not* coincide. This is not realized by many investigators. Further, a given area of stress can be associated with several remodeling fields that have quite different behavior. A single muscle, for example, is often attached onto a widespread surface within which some areas undergo resorption while other immediately adjacent regions are depository. All areas have a common vascular supply, the same nervous innervation, and so forth. How muscles can attach directly onto *resorptive* bone surfaces was previously described in relation to the resorptive side of the alveolus. Also, fields of tension frequently pull in one direction while the underlying bone grows in another. There is no doubt that stresses can serve as a trigger for remodeling (category 2 above). How this is translated into an actual tissue response by the next sequential factor in a chain of control factors is not now understood. Processes such as the piezo effect are often suggested. It is also possible that stresses may function in a strictly supportive or secondary role in some instances.

**HEREDITY.** The two conventional conceptual extremes are well known: genes serve to directly or indirectly govern most skeletal and growth remodeling activities throughout life, or gene action is not involved beyond the early establishment of the fetal skeleton, and other (presumably biomechanical) factors then determine the course of activity. The geneticist "school" counters the latter with the argument that extrinsic forces serve to variably determine the nature of *selective* genetic expression and programming for that particular tissue according to the changing conditions present. The biomechanical school responds with the presumption that insufficient genes exist to account for all of the complex, localized architectural details of all the different bones of the skeleton (see *Enlow, 1968b,* for a further evaluation). These arguments will continue until the basic nature of the complete, overall control process itself becomes satisfactorily explained, and such arguments as the foregoing will then become meaningless. At the present time, many investigators attempt to draw a line at some theoretical point between heredity and environment. Why, at this time, must we be required to do this at all when the basic information needed is still insufficient? Whatever might be the variable *balance* between them (and also the other factors described below), it is apparent that any genetic influence must become expressed by osteogenic *soft tissues* and not by the components of the actual hard part of the bone itself. With regard to the classification system described above, the factor of heredity can be identified with the last three categories.

**HORMONES.** These are systemic control factors, and we are presently concerned with *local* mechanisms of tissue regulation. With regard to the classification system, however, hormones would be represented largely by category 2 or 4. See also under "chalones" below.

**NUTRITION.** Although nutrition is largely a "supportive" rather than a primary agent in the sense used here, its importance in periodontics and prosthodontics is of course basic *(Israel, 1967; and Garn, 1970)*.

**INDUCTION.** The introduction of this principle nearly a half century ago was regarded as a major conceptual breakthrough, and it created a great deal of interest and excitement in developmental biology at the time. The induction concept, however, has been largely dormant in our own field of bone physiology for many years but has recently experienced a major revival *(Urist and Strates, 1971)*. The process itself describes the stimulating and triggering effect of one tissue directly on another contiguous tissue. The physiochemical agents involved are still virtually unknown.

A *single* "inductor" substance, historically, was sought which would then presumably represent the universal bone tissue control agent. This notion is now realized to be naive since a *complex* or a chain of factors must be involved. In transplant studies of tooth buds into the developing connective tissue of the skin in hamsters, Hoffman *(1960)* observed that these buds exert a definite organizing (inductive) influence and result in the differentiation of a periodontal membrane and alveolar bone tissue from the connective tissue anlage.

Induction is a "title" for a control process (category 3), and its mechanism of actual operation is not accounted for. The importance of the process itself, however, must be recognized.

**NERVES.** A great deal of evidence has accumulated that nerve fibers can in some (but not all) circumstances be directly implicated in a chain of control-response actions during bone growth or remodeling *(Moss, 1971)*. This is believed to involve the production of a neurotrophic humor (an undetermined hormone or enzyme) which is secreted at a nerve ending, either sensory or motor. Different nerve-muscle-connective tissue-bone pathways appear to be involved. This substance(s) appears to have a specific inductive effect upon selectively sensitive tissues in localized areas.

This hypothesis is attractive and, in principle, represents a multifactorial approach to the overall problem of control that is promising. It should not be presumed to be a total explanation for growth control but may well prove to be a significant part of the overall regulatory process.

**VASOMOTOR CONTROL.** While undoubtedly involved during tissue differentiation and remodeling, this process can only represent an intermediary factor. It can be classified under either 2 or 4 above. Vasomotor influence may be expressed several ways: a hydraulic effect on surrounding tissues; increasing or decreasing *local* supply of nutrients, oxygen, etc.; temperature control; and (indirectly) endothelial induction and/or proliferation.

**ENZYMES.** These are involved as a basic part of *any* kind of tissue control mechanism. The problem, of course, deals with *which* enzymes and enzymatic chains, and the specific nature and extent of their various differential activities. It is certain that a complex array of enzymatic agents plays a variety of selective roles in the overall control process, both in bone formation (alkaline phosphatase, etc.) and bone resorption. These cover categories 2 through 4 in the classification system above.

Bone resorption is a two-phase operation involving first the demineralization of the inorganic matrix followed by the removal of the exposed organic matrix. Although the mechanisms for these two processes are entirely different, they usually proceed in concert with each other and at the same rate. Resorption of the organic phase of the matrix iteself requires a two-part process: removal of the collagenous fibers and removal of the mucopolysaccharides of the ground substance. Although generalized "proteinases" may be responsible for this entire process, it is likely that specific collagenases as well as polysaccharidases are involved.

Contrary to most statements in the literature, a total resorption of both the organic and inorganic phases is *not* always a required feature of the resorptive process *(Bohatirchuk, 1966; Gussen, 1968a, 1968b)*. In fact, the maintenance of membrane attachments onto resorptive surfaces in certain areas *depends* on a differential process of exclusive inorganic but not fibrous removal *(Enlow, 1968a)*.

When the *organic* matrix is destroyed during resorption, various enzymes are believed to be the agents that are directly involved *(McLean and Urist, 1955)*. Vaes *(1968)* has proposed that acid hydrolases of lysosome origin are specifically responsible for this function. Kaufman, *et al. (1966)*, using $H^3$-hydroxyproline, have shown that a "collagenolytic factor" occurs within the bone substance which is undergoing active resorption. The presence of collagenase in compact bone has also been reported by Lapiere and Gross *(1963)*. Aminopeptidase *(Lipp, 1959)* was identified in those osteocytes associated with the process of lacunar osteolysis (this special resorptive mechanism is discussed later). The possible protective properties of fluoride, interestingly, have been explained by Rodan and Anbar *(1967)* as the direct inhibition of such enzymatic actions. Goldhaber *(1967)* also states that fluoride functions either to interfere with enzymatic cell activities or to "stabilize" the bone mineral. Sognnaes *(1965)* has even suggested that a topical application of sodium fluoride can be used for the treatment of localized bone resorption.

With regard to the trigger which acts to stimulate the secretion of enzymes involved in bone resorption, Stern, *et al. (1963, 1965)*, Goldhaber *(1963)*, and Walker, *et al. (1964)* believe that parathyroid hormone functions, at least in part, to increase the production and the release of those enzymes having a specific collagenolytic action. Talmage *(1967)*, however, maintains that parathyroid activity serves largely to stimulate the differentiation of additional numbers of new osteoclasts from "mesenchyme," and that the overall effects of the hormone are due to this action rather than any increased secretory output by the osteoclasts already present.

**TEMPERATURE.** Local changes in tissue, cellular, and intercellular temperature levels by vascular control and by local muscle or metabolic activities have long been known to exert a wide variety of physiological effects in most tissues. As a control factor, however, temperature takes part in an essentially intermediary, supportive, or catalytic capacity. In some instances, temperature changes are merely an effect rather than a cause.

**FEEDBACK MECHANISMS.** These are certainly involved. There are many different types of self-regulating feedback systems among the different functional and biochemical interrelationships of body parts and organs. These include physiologic balances (as in ionic calcium regulation, *Buckle, 1970*) and tissue adjustments (as in coordinated bone/muscle/nerve growth). The neurotrophic process previously discussed utilizes a direct feedback system. The "feedback process," of course, is a *title* for a process and does not account for the actual modes of operation of the process itself (category 3).

**THE pH FACTOR.** The relative acidity of the bone surface milieu has long been regarded by some as the direct causative agent that accounts for bone resorption, and it is also believed to be involved in bone formation as well *(Bassett, 1962)*. An acid (perhaps phosphoric acid), presumably secreted by osteoclasts, for example, has been cited as a possible means involved. Such concepts in general, however, have undergone a number of modifications that require sophisticated biochemical cycles and which may also involve a number of agents, including chelators. Whether or not pH itself is a *direct* resorptive factor, as in the solubilization of mineral, is not clear, but hydrogen-ion potential may be closely related to the recent concepts involving electric charges on bone surfaces. However, it is well established that bone resorption is a two-phased operation, as previously noted, and that the mechanisms that bring about the organic part of resorption are separate from those involved in the removal of inorganic portions. McLean and Urist *(1955)* and Nichols, *et al. (1965)* state that resorption first requires the extraction of the mineral by a change in pH or the liberation of a chelating agent. This is followed by resorption of the exposed organic matrix (fibers and ground substance) by enzymes. In a recent tissue culture study, Vaes *(1968)* demonstrated the removal of organic components from bone by the acid hydrolases of lysosomes and, in the same culture, release of minerals by the "acids" presumably associated with glycolysis.

**OXYGEN LEVEL.** The proximity of a capillary has a direct influence on the determination of the immediate site of initial ossification in an area of bone formation. Relative extracellular oxygen tension levels together with ionic calcium levels, nutritive supply, and the stimulus of localized enzymatic agents are all involved. Bone characteristically develops, and calcification proceeds, at a place of origin that is the geometric point *farthest removed* from neighboring blood vessels *(Enlow, 1968a)*. Functionally, the osteogenetic process could only proceed in this way since it is not possible for deposition to begin adjacent to the vessel and then continue in a peripheral direction away from the vessel. In a series of *in vitro* studies, Bassett *(1962)* has shown that oxygen tension directly influences the selective development of a bone/cartilage type of matrix. He found that formative cells can behave either as chondroblasts or osteoblasts depending upon the availability of oxygen. Fell *(1932)* had previously shown that direct transformation from cartilage to bone can occur in cultures. Cartilage, in contrast to bone, is a nonvascular type of tissue that can exist in the absence of a covering membrane (as in the articular cartilage).

**DIFFERENTIAL CELL RESPONSE.** This consideration is a definite factor in control, but it is a "title for a process" and not explanatory of the actual mechanisms involved (category 3). What provides the direct control for the variable sensitivity of cells to stimuli, and in turn, the behavior and response by the cell? Genetic programming, membrane permeability, nuclear-to-plasmalemma links, differential enzymatic exposure, and many similar factors must all necessarily be involved.

**DIFFERENTIAL MEMBRANE PERMEABILITY.** Like the preceding factor, membrane behavior is certainly involved but must itself be explained. The subject of membrane physiology represents a vast field of present-day investigative effort, and the nature of membrane models and the agents of differential membrane control are of great interest and importance. Unfortunately, these subjects are generally poorly represented and understood by most bone biologists.

**CYCLIC AMP.** The multiple functions of this substance as a hormone intermediary are directly relevant to bone remodeling control. Also, its role as a mediator between nucleus and cell membrane is to be regarded as significant in differential cellular expressions and behavior in the membranes associated with bone. Cyclic AMP, and other related substances perhaps yet to be recognized, are now certain to become a focal point of interest in the field of regulatory biology. Bone investigators should keep close watch on forthcoming advances.

**BIOELECTRIC POTENTIALS.** This was the great hope of the 1960's, and although the long-sought breakthrough has not been forthcoming, much interesting work has been done and is continuing. The basic idea is, essentially, that mechanical deformation of the crystalline components of bone by any given physical stimulus generates a charge (the piezo effect) which, in turn, affects the surface membrane of bone-forming and resorbing cells and triggers their activity *(Bassett, 1965, 1966, 1968)*. While studies have been somewhat encouraging and certainly of great interest, the premise that this is *the* control mechanism, as hoped, is still in need of basic documentation. The practical utilization of this principle for the clinical control of bone remodeling is not yet in sight.

Most studies dealing with bioelectric relationships have been concerned with the piezo effect. However, it is possible that charge potentials may exist in relation to the bone surface which are independent of any crystal-stress origin. The characteristic fields of remodeling present in all bones *(Enlow, 1968a)* may be related (either as cause or effect) to corresponding electric "fields." Although the nature and origins of such electric potentials are still speculative, such distinct bioelectric fields do exist *(Friedenberg, et al., 1971)*. The latter investigators have shown that positive and negative "field potentials" are correlated with resorptive and depository remodeling fields. Basic work now needs to be done in order to determine any possible trigger-response relationships.

**INHIBITORS AND STIMULATORS.** An interesting concept that has emerged strongly in the last decade dealing with the remodeling and growth control of soft tissues is that these tissues in effect are programmed to undergo cell division and differentiation at maximum capacity. Regulation is provided by variably *inhibiting* or suppressing the growth activities of some selected, localized cells or whole communities of cells. Inhibition is provided by a newly recognized kind of *local* (not systemic) "hormone." This mode of remodeling control has been worked out and documented in studies of cutaneous growth and differentiation *(Bullough, 1967)*. The inhibitor itself has been termed a "chalone," and the principle involved is currently of great interest with regard to other types of tissues. It has been suggested that "stimulators" may also exist as counterparts or antagonists to such inhibitors. Remodeling, growth, and differentiation would thus be controlled by a composite process of mitotic acceleration and braking at selective, localized sites, thereby providing proliferation as well as differentiation and, also, coordination between different growing, changing tissue masses.

These control mechanisms represent, in effect a *local tissue* counterpart of similar "balance" systems at the systemic level. For example, parathyroid hormone and thyrocalcitonin provide such reciprocal, antagonistic, stimulatory and inhibitory functions *(Friedman and Raisz, 1965)*. It has long been a visionary goal of investigators to develop two such simple single substances that, when administered to a patient in a controlled way, can either accelerate deposition or resorption selectively. Pechet, *et al.* *(1967)* state that thyrocalcitonin and neutral phosphate represent, at least theoretically, two such substances.

**EFFECT OF REMODELING CHANGES ON SUBSEQUENT GROWTH PROGRAMMING.** A basic and important question is whether remodeling alterations of bone (natural or experimental) can affect and directly change the future course of remodeling activity or, conversely, whether subsequent remodeling will proceed according to an already prescribed program which is not influenced by any subsequent remodeling events. This is of great interest and significance to the clinician since the structural effects of treatment can become lost if future changes proceed independently of clinically induced alterations. The answer to this question will not be forthcoming until the question of the basic control mechanism itself is resolved.

**GRAVITATION.** Many accessory factors such as gravity exist that are known to affect bone remodeling in a secondary manner. They can have importance in their own right, such as the field of skeletal physiology involved in space medicine. Reduced gravitation, lessened body weight on the bones, decreased muscle pull and its effects because of reduced weight, lessened muscle tonus and lack of body-to-ground contacts are all believed to have biomechanical effects resulting in bone loss *(Bassett, 1966)*. As in all control systems, however, the basic mode of actual operation cannot at present be explained.

**THE FUNCTIONAL MATRIX.** This concept *(Moss, 1971)* has been of considerable interest and value to the bone biologist because it has called special attention to the real location of control within the soft tissues associated with the bone rather than the bone itself. It had long been customary to view bone as a more or less independent anatomical unit that remodels as a consequence of its own intrinsic control. Bone, however, is a *product* of the enclosing soft tissues, including the periosteum, and it is entirely dependent upon them for the source of virtually all direct remodeling activity. Reciprocal feedbacks between bone and soft tissue exist, however, so that the combination represents a mutually interdependent control system.

The functional matrix concept is a descriptive title that, in effect, is synonymous with the "control process" but does not explain the underlying nature of its operative mechanism. One must not misuse this concept, thus, in a way that implies that the functional matrix is the actual regulatory process itself (rather than those control agents that constitute the functional matrix), and that it accounts for the details of remodeling control. The functional matrix is a *description* of the basic process of control and not an *explanation* of it.

**PHYLOGENETIC CONTROL.** A basic theoretical question is whether or not the factors that have governed the long term evolution of skeletal features are the same factors which control tissue development from fetus to old age. Are the phylogenetic control factors that have brought about jaw "reduction," for example, the same intrinsic factors responsible for the prenatal and postnatal histogenesis of the jaws? The answer must await the basic answers to all of the preceding questions of control.

In conclusion, it is significant that we are entering a period in which we can, for the first time, meaningfully *recognize* the basic problem of localized tissue control and to define it. In itself, this is to be regarded as a significant advance since our use of misleading concepts, such as the belief in and the unrestricted acceptance of Wolff's Law as a virtually complete principle, have actually retarded effective progress in recent times. It should be realized that many diverse fields in biology are actively concerned with essentially the same basic problems of control that we have encountered in bone biology. Yet, regrettably, we have largely isolated ourselves as a group and have not always sought out that which can be profitably offered by many other present-day areas of investigation. It is quite likely that *they* will contribute in a major way to the breakthroughs so badly needed in our own field.

## ALVEOLAR REMODELING AFTER THE CHILDHOOD GROWTH PERIOD

Following the loss of teeth, the fundic portion of the socket begins to fill with osteogenetic connective tissue and progressively developing fine and coarse-cancellous bone. The alveolar processes themselves begin to regress, and a variety of characteristic structural types of residual (edentulous) ridges eventually form *(Atwood, 1971)*. This process and the nature of the resultant residual ridges are of considerable importance since these ridges are subject to continued remodeling alterations, particularly in conjuction with dentures. The long term stability of the denture is at stake. Because of these factors, much interest currently exists in the basic physiology of alveolar bone and its normal and abnormal behavior as a specific tissue type.

Using microradiographic methods, Manson and Lucas *(1962)* have shown that generalized remodeling activity occurs at a much higher rate in alveolar bone than in the adjacent corpus of the mandible. Baumhammers, *et al. (1965)* also demonstrated, using $H^3$-proline labelling in experimental animals, more active deposition as well as resorption in alveolar bone than in the nontooth-bearing bone tissues. The latter investigators related this to the normal physiological movements of teeth and also to the greater vascularity of the alveolar processes as contrasted with the denser tissue of basal bone. They also found, interestingly, that the rate of both formation *and* resorption tended to slow with age, a finding similar to that previously reported by Amprino and Marotti *(1964)*.

The extent of overall remodeling activity, in general, is correlated with the relative extent of the surface bone exposure present *(Enlow, 1968a)*. Bone "surfaces" can exist in several forms *(Enlow, 1963)*: periosteal and endosteal cortical surfaces; lining surfaces of cortical vascular canals (the greater the number of canals, the higher the net rate of *internal* reconstruction within the cortex); the lining surfaces of lacunae and canaliculi; and the surfaces of fine and coarse-cancellous trabeculae. Because the latter type presents a much larger aggregate surface exposure than the others, the net amount of surface activity is much more extensive in cancellous bone, both by resorption-deposition remodeling and by surface ion-exchange.

Atkinson *(1969)* and Atkinson and Woodhead *(1968)* have called attention to the above features with respect to alveolar bone. They point out, first, that alveolar bone is much more porous in nature than basal bone, and that this is a basic pattern that actually begins in childhood. They then show that increasing resorption is more evident in the alveolar areas and correlate this finding with the characteristically more porous nature of the alveolar bone. The basal bone tissue, which is of a much more compact type (less vascular), tends to remain dense and, indeed actually *increases* in density with age (Israel reports a similar finding, as discussed below).

With regard to alveolar crest recession during aging, Atkinson and Woodhead *(1968)* have noted that porosity increases on the *buccal* side of the alveolar cortex in the incisor region but not on the lingual side. This would tend to shorten the arch. In the molar region, density decreases (porosity increases by resorption) primarily on the *lingual* side of the alveolar cortex, thereby tending to widen the arch with age. Israel *(1967)* has shown that overall height of the mandible *decreases* yet cortical thickness itself *increases* at the same time. He states that this occurs over a 40 year period in males and a 50 year period in females. Further, he reports that the facial and cranial bones, in general, are unique in that new bone deposition during long-term aging is in excess of resorption. This, interestingly, is in contrast to other elements in the skeleton.

As mentioned previously, the physiological nature and functional behavior of the residual alveolar ridge following loss of teeth is of considerable importance with regard to long-term denture stability. Although recession of the alveolar processes after dental loss is itself a normal and an essential process, the remodeling of this ridge can properly be defined as a major "disease" from the point of view of denture obsolescence. As Atwood *(1971)* has emphasized, this basic clinical problem remains unsolved. Atwood has described the histogenetic process of residual ridge formation. The periosteal surface of this ridge, in brief, is resorptive in nature and, following the "V" principle, endosteal deposition of new bone by cancellous compaction moves the thin cortex in a direction toward the basal bone. Atwood has also described and classified the various morphological forms and types of edentulous ridges that are commonly encountered.

In a study of changes following experimental tooth extractions in monkeys, Pietrokovski *(1970)* found that remodeling of the edentulous ridge is essentially complete within an eight-week period of healing. Beyond this, the morphology of the ridge becomes essentially stable. He also noted that alveolar resorption in these animals was limited by the boundaries of the attachments of muscles. He suggests that, unless some additional intrinsic or extrinsic factors become involved (such as denture wearing or systemic disease), adjacent muscle attachment sites impose the normal limit for the extent of alveolar regression. Sobolik *(1960)* comments that *many* factors can accelerate and extend alveolar bone atrophy, including diabetes, tuberculosis, duodenal ulcer, hyperparathyroidism, dietary deficiencies, and trauma. That such factors in man can intervene and extend alveolar resorption is common, and Atwood *(1971)* states that reduction of the residual ridge appears to be potentially unlimited and can go on for years until it extends below muscle attachments, the genial tubercules, and the mylohyoid line.

As the residual ridge undergoes remodeling regression, surface "defects" are seen to occur on the ridge. The significance of these scattered, erosive patches is not known, but they appear to be unique to alveolar bone *(Nakamoto, 1968)*. Nakamoto points out that such defects are not always merely partially healed remnants of remodeled sockets, as commonly believed, since they are also observed in non tooth-bearing areas.

Pietrokovski and Massler *(1967)* have traced the directional course taken by the alveolar ridge as it undergoes regressive remodeling. They found that the maxillary buccal plate shifts to a position that is closer to the palatal plate since resorption of the buccal plate exceeds that of the palatal plate. This change produces a reduction in arch length (see also Atkinson and Woodhead). In the mandible, the ridge also shifts in a lingual direction because the buccal alveolar plate resorbs more than the lingual plate. This change results in a shortening of overall arch length. They also noted that resorption was significantly greater in the edentulous molar region than in the incisor and premolar regions, both in the maxilla and the mandible.

With long term wearing of dentures, Tallgren *(1967)* reports a continued reduction of the remaining bone of the ridge. This produces a marked decrease in overall face height. Anterior rotation of the mandible also contributes to a reduction in the vertical dimension of the face and, of course, to increased mandibular prognathism. Significantly, she did not observe cephalometric changes in the cranial base, upper face, or in the basal parts of the mandible despite marked alveolar resorption. She also noted that reduction of the alveolar process was approximately four times greater in the mandible than in the maxilla.

## ALVEOLAR BONE LOSS

If alveolar bone becomes lost or otherwise affected in some severe manner, the teeth are then lost in turn. Similarly, if a tooth is lost, the alveolar bone related to it subsequently undergoes *destructive* resorptive changes while, at the same time, the fundic part of the socket becomes filled by a *constructive* bony buildup. What are the causative and, particularly, the control processes in such contrasting, regionally differential, interdependent responses? As previously described, a great many different factors or regulatory processes appear to be directly or indirectly involved. The conceptual obstacle encountered is the same lack of fundamental understanding of the operation of the complex control mechanisms involved. Until this dilemma becomes resolved, there will be no way to design a rationally-based clinical procedure to control the control process itself. A number of actual and theoretical possibilities exist, however, as to general causes and the underlying reasons for alveolar bone and/or tooth loss. These are described below.

Israel *(1967)* properly points out that two general categories of tooth loss exist; loss as a consequence of periodontal disease, and tooth loss as a direct or indirect result of some intrinsic condition or remodeling change in the alveolar bone itself. It is the latter consideration that is relevant to the present review.

The "bone factor" has long been regarded as meaningful in diagnosis and includes whatever pertinent features and characteristics of bone tissue physiology that exist in a particular individual. Israel *loc. cit.* emphasizes this with respect to the findings of Garn, *et al.* *(1966)* dealing with "normal osteoporotic bone loss" and also the experimental as well as the clinically observed relationships between osteoporosis and loss of dentition *(Groen, 1960; Zipkin, et al., 1965)*. It appears probable that generalized skeletal osteoporosis which extends into tooth-bearing bone can represent at least one major, primary cause of the eventual loss of the dentition. As is well known, the broad subject of osteoporosis* has long been one of the most active but controversial areas in medical research *(Frost, 1960, 1963)*.

Atkinson and Woodhead *(1968)* and Duterloo, *et al.* *(1971)* have proposed a most interesting type of possible correlation between the nature of the osteoporotic process and subsequent tooth loss. The mandible and maxilla (and all other bones as well) have characteristic, mosaic patterns of resorptive and depository "fields" within the covering soft tissue membranes and the bone surfaces. These fields blanket all periosteal and endosteal surfaces of the cortex and all surfaces of the cancellous trabeculae as well. They bring about the progressive growth of the whole bone and, at the same time, provide the remodeling that accompanies growth *(Enlow, 1968a)*. These fields are, in effect, the actual receptors of any control factors that act on the bone. The above authors have suggested osteoporotic resorption is an adult continuation and a counterpart of the same process of resorption that is concerned with childhood skeletal growth. They state that the geometric pattern of distribution of the porosity changes in osteoporosis coincides with the resorptive fields that were formerly present in the growing mandible, and they suggest that the osteoporotic pattern is directly established by these early remodeling fields. They show that, shortly after maturity, signs of involution begin to appear in the specific areas where resorptive fields had previously occurred during the earlier growth period. In the human mandible, further, they observed that the distribution of the porous types of bone (which have been shown to be most involved in resorption) prior to the onset of osteoporosis also coincide with the distribution of the resorptive growth fields that had existed during former growth periods of the bone. Atkinson and Woodhead state that "the pattern of osteoporosis is a direct result of an inbuilt predisposition to resorption which was established during growth. Such changes in the bone appear to be a major cause of tooth loss in the adult rather than the result of it." They also comment that this osteoporotic process is not dependent on the presence of teeth but rather is a generalized process that occurs in both tooth-bearing and nontooth-bearing parts of the mandible.

*A method has been newly developed that promises to detect subtle, beginning resorptive changes on trabecular surfaces of cancellous bone *(Oxnard, 1972)*. This procedure might be used to "predict" the onset of osteoporosis and thereby also predict possible dental losses in the future as well as the specific locations that are likely to be involved. The method involves the identification of complex geometric patterns by optical filtering, two-dimensional Fourier analyses using coherent light.



Four other possibilities in the etiology of alveolar bone loss, also, should receive further study. First, Gianelly's suggested relationship between the hydraulic action of periodontal vessel dilation and its effect on the alveolar bone surface (perhaps by the piezo effect) might be involved as a factor in alveolar regression.

Second, the process of Haversian reconstruction is known to be involved in the replacement of aging and necrotic bone tissue *(Enlow, 1962; 1966)*. All bone has a normal life span of several years, depending on the density of vascularity. When necrocytosis occurs, replacement by secondary Haversian bone eventually occurs. *It is suggested that this process of internal bone replacement within a cortical plate can directly remove that bone formerly providing periodontal fiber attachment and thereby result in progressive release of the fibrous membrane.* The process of osteoporosis itself may, in part, be the result of an interruption of such a replacement mechanism. That is, the *resorptive phase* of Haversian reconstruction occurs, thereby producing widespread, enlarged Haversian erosion spaces, but the subsequent *depository phase* does not follow so that the cortex becomes reduced to a porous state.

Third, the destructive process of "osteolysis" *(Bélanger, 1970)*, which is a localized process of resorption of the bone matrix by lysosome-loaded *osteocytes* (not osteoclasts) in the immediate areas surrounding these cells, is known to occur in normal physiological conditions as well as in diseases characterized by excessive resorption *(Whalen, et al., 1971)*. The latter investigators have attempted to show that such localized resorption can produce a widespread, aggregate resorptive effect. Baud and Auil *(1971)*, importantly, report that "alveolar bone is a *preferential site* for the development of osteolytic changes."

Finally, a study by Gussen *(1968a)* is of considerable interest. She describes for the first time a previously unrecognized type of bone remodeling or, more properly, cortical reconstruction. This process was observed in the labyrinthine capsule of the temporal bone and involves partial or complete, localized demineralization of bone matrix and a depolymerization of the ground substance specifically in perivascular areas. Bone cells in such restricted regions undergo atrophy, and new osteocytes develop from the undifferentiated cells associated with the perivascular connective tissue. Repolymerization of the matrix follows, and this perivascular area then becomes remineralized. This is a local rebuilding process that does not occur in all cortical areas at the same time. Wherever it occurs, the result is bone tissue that is essentially the same as that which had been replaced. The process itself can thus be difficult to recognize, particularly in decalcified sections. This unique process has, to date, been observed only in the bone of the labyrinthine capsule; alveolar bone has not yet been studied. Belanger, *et al.* *(1963)*, however, have demonstrated a relationship between osteocyte activity, as in the process of osteolysis previously mentioned, and the process of bone matrix depolymerization. Further, Heller-Steinberg *(1951)* demonstrated that, in such a depolymerized state, the bone mineral becomes more highly reactive. Although the meaning of these various studies is not clear at this time, possible relationships to alveolar bone remodeling are apparent and should now be investigated.

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# SECTION REPORT

## INTRODUCTION

The Section on "alveolar bone" felt strongly that its purpose was to discuss and then collate newer knowledge on bone as it applies to clinical complete denture prosthodontics. There seems to be no need, nor is it possible in this length of time or under these circumstances to present a document describing the present day scheme of bone biology in textbook fashion, but rather it seems better to present some guidelines under which direction for future clinical practice and research can follow and to ask some rather important questions which unfortunately are not answered by the data that we have today.

Aging studies and recent work on osteoporosis were discussed in length along with the control mechanisms of bone and the present status of osseous tissue as it is directly involved with complete dentures.

Although the Section could not possibly agree with the divergence of our backgrounds on all points, it decided not to demand a consensus, but rather to present some generally accepted concepts along with areas of major dissent. At various points in its report, the Section asks pertinent questions which need to be answered. These are deliberately not philosophical, but questions that can be answered with methodologies available to prosthodontists today.

The goal of this Section has been to relate basic knowledge about bone to the practical problems of complete denture prosthodontics.

## GENERAL PHENOMENA OF ADULT CRANIO-FACIAL BONE CHANGES

Today special emphasis is being placed upon understanding human aging. The totally edentulous patient is wrapped intimately in this process of aging. The skeletal system places enormously restrictive burden upon the individual when it begins to fail as it often does in older age, especially in females.

It is now known that many bones in the postcranial skeleton, that is the skeleton below the cranium, waste with age. After about 40 years



of age, bone destruction exceeds formation with a net result in thinn bones which become increasingly less capable of maintaining a supporti function. In bones such as the femur, metacarpal, radius, ulna, and ri subperiosteal apposition exceeds resorption and endosteal resorption e ceeds formation thereby giving an enlarging diameter effect along wi the thinning of cortical bone. Trabecular alteration occurs concommitant and this involves reduction in numbers of trabecular, and thinning the trabecular, and reorientation in direction of the remaining trabecula

Now it is felt that the cranio-facial complex is no exception to tl aging process. Recent studies in white women over the age of 25 ar up to the age of 90 years give clear evidence that the skeleton of tl neural and visceral cranium continues to grow throughout life. This pote tially has significance relating to the field of complete denture prosthodo tics though it will be necessary to amplify the initial results of this tot concept in light of the possible effects.

To summarize some of these observations, surface apposition and r sorption seem to be the method bringing about these changes. The cran um in the frontal region thickens about 12 to 14% while the more dist parietal and occipital sections are less prone to this effect. Overall neur cranial skull diameter also increases, but only about 6 to 8%. Both th outer diameter and the cranial cavity demonstrate expansion. The faci compartment although of limited evaluation shows the same magnitud of change as does the mandible and the cranial base. The frontal sinu and the sella turcica enlarge but their change is greater than face, skul or mandible, and in the range of 10 to 15%.

In essence then, the cranio-facial complex is in a state of growth throug out life. The entire system seems to be involved by symmetrical enlarge ment. For example, studies have shown the mandibular body increase in its gross diameter 6 to 8%, but neither age nor loss of teeth hav been shown to modify the mandibular angle over extended time. Th loss of teeth does not appear to alter the condylar and coronoid processe as usually depicted in anatomy texts. In all likelihood the mandible thicken with age as it enlarges in other dimensions. *This then leaves the tooth bearin process as the area where the well known pronounced bone loss changes ca occur concurrently to the overall enlargement of the jaw.* At the present tim there seems to be no way to separate the alteration in tooth bearin bone on the basis of either age and/or periodontal disease alone.

Whether continuing cranio-facial growth during adulthood profoundl influences prosthetic dental management is problematical but the overal aging concept of the cranial skeletal is now clear, just as are the simila alterations in the appendicular and axial areas. We have interposed few questions at various points in this report.

What age, sex, and race factors are operational in residual bone loss?

## ALVEOLAR BONE

The Section objected to the term *"alveolar"* in the edentulous subject and preferred the term *"residual bone"* for the following reasons:

1. There are no longer any alveoli in the edentulous subject.
2. *Morphologically* (both grossly and microscopically), one cannot differentiate between "alveolar" and "basal" bone in the edentulous subject.
3. *Physiologically,* one cannot differentiate between "alveolar" and "basal" bone in regard to such entities of bone as osteocytes, osteoclasts, osteoid seams, tetracycline and radioactive isotope uptake, vascular channels, etc.
4. *Residual bone* is that bone which remains after the teeth are lost.
5. The *residual ridge* is the residual bone and its soft tissue covering.

**GROSS MORPHOLOGIC CHANGES OF ALVEOLAR AND RESIDUAL BONE.**

1. There is some evidence that even if teeth are retained, the periosteal circumference, or superior-inferior height of the mandible decreases with aging.
2. Incomplete data exists with respect to changes which occur when teeth are lost and no dentures are worn. Available data and clinical observations suggest a lesser loss of residual bone in nondenture wearers than in denture wearers.
3. With loss of teeth and the insertion of dentures, there is commonly bone loss. The magnitude of this loss is extremely variable and we have no way at present to identify those who will lose minimal bone loss and those who have a rapid, progressive loss of residual bone.
4. We must more carefully look at available data and collect new data in an attempt to clinically identify those problem patients, i.e., those who rapidly lose bone following tooth loss.

**HISTOLOGIC CHANGES IN EDENTULOUS ADULT MANDIBLE (RESIDUAL RIDGE).** There are no unique histologic features of mandibular alveolar bone. It is composed of various forms of cortical and trabecular patterns. However, in edentulous adults it has been observed that all varieties of bone patterns, from dense cortical to fine trabecular, exist in the residual ridge area.

We do not know the relation between these various bone patterns and the sequence of modeling and remodeling events which occur following tooth loss. These must be studied.

Biomechanically, although one can theorize a number of relations between these various bone types and different types of changes in forces applied to the mandible after tooth loss, actual data on such changes in forces in the mandible are not available.



Moreover, we do not know the difference in the histologic and hist[illegible] namic nature of those patients who rapidly lose bone after denture in[illegible] tion and those who lose little bone.

### *Questions Which Need To Be Answered.*

What type of bone is most conducive to maintain residual bone?

Is there any way to make a prediction about ridge maintenanc[illegible] any given patient?

What is the life history of the reduction of residual ridges? How d[illegible] the bone remodel?

What is the relation between the type of bone at the resorptive mar[illegible] of the residual bone and the rate of reduction?

## OSTEOPOROSIS

Osteoporosis is a disease of decreased bone quantity and/or qua[illegible] which diminishes the capability of the skeleton to function as a supporti[illegible] structure.

Morphologically, osteoporosis is characterized by thinner cortices, th[illegible] ner and sparser trabeculae with resulting increased marrow cavity si[illegible] Osteoporosis can be thought of as:

**OSTEOPOROSIS OF AGING.** All individuals experience a continu[illegible] progressive loss of bone mass following skeletal maturity. The gene[illegible] mode of loss is similar in nearly all bones studied. The mandible, followi[illegible] tooth loss, is an exception (i.e., periosteal circumference decreases here

**PATHOLOGIC OSTEOPOROSIS.** Bone loss resulting from recogniz[illegible] conditions, e.g., senile osteoporosis, postmenopausal, hyperadrenal c[illegible] tism, thyrotoxicosis, etc.

**LOCALIZED OSTEOPOROSIS.** Local bone loss occurs following su[illegible] things as denervation, muscular atrophy, immobilization, etc., indepe[illegible] dently from a generalized systemic loss of bone.

### *Questions Which Need To Be Answered.*

Is there a relation between generalized skeletal loss (osteoporosis) an[illegible] reduction of residual bone following tooth loss?

How much is edentulous mandibular bone loss secondary to dentu[illegible] wearing? What evidence signifies correlation between mandibular bon[illegible] loss and denture wearing?

## CONTROL FACTORS

There are numerous suggested control factors at the genetic, systemic, and local level for the control of modeling and remodeling behavior. It appears from available evidence with respect to loss of residual bone following tooth removal and insertion of dentures, that we are dealing primarily with local control mechanisms. This does not, however, preclude the possible effects of systemic and genetic factors.

Some of the local control mechanisms which have been experimentally investigated include biomechanical factors, neurotrophic factors, vascular, chalones—local hormones, enzymes, pH, bioelectric potential, gas tension, temperature, nerve and neuromuscular reflex.

With respect to complete denture prosthodontics, we have little knowledge about how this wide variety of local control mechanisms may cause reduction of residual bone.

## PROSTHETIC FACTORS

The development and maintenance of the alveolar process is directly related to the eruption and presence of the dentition. The occlusal pressures are translated into forces expressed through the periodontal membrane. Proprioceptive and biomechanical stimuli may be instrumental in the maintenance of the alveolar process.

Two concepts have been advanced concerning the question of the inevitability of loss of residual bone. One contends that when the teeth are lost, there is a variable progressive residual bone loss. This modeling is regarded as a direct consequence of the elimination of the functional demands imposed by the teeth through the periodontal membrane. Further, according to this concept, the resorption of the ridge is a typical phenomenon, and the lack of resorption represents an atypical condition. The other concept maintains that residual bone loss is not a necessary consequence of tooth removal. The rate of bone loss is highly variable, dependent upon a series of poorly understood factors.

Imposition of a prosthesis introduces alien forces into the oral cavity and creates (as far as the residual bone is concerned) a functional situation which is totally contradictory to that encountered in jaws bearing teeth.

The problem confronting the prosthodontist is to determine the mechanisms through which the loads transmitted through the prosthesis are translated into resorption and to develop a technique for arresting the resorptive mechanism. This resolution is probably dependent upon a determination of the nature of local control factors affecting bone remodeling.



## CONCLUSION

It appears obvious that current practices in complete denture pros dontics have not solved the problem of the maintenance of residual b Therefore, new approaches must be continually sought to accom this end while continuing to examine and re-evaluate those known fac

Until such time as bone physiologists can tell us how to build b bone, we must do all that we can to conserve bone. In the meant if the bony base on which we build our occlusion changes, then complete denture occlusion must necessarily change.

Respectfully submitted,

Douglas A. Atwood, *Chairman*
Davis Henderson, *Secretary*
Donald H. Enlow, *Reviewer*
Oliver C. Applegate
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# DISCUSSION OF REPORT

Following the reading of the Section's report by Atwood, a motion was made by Henderson and seconded by Applegate for its acceptance. The motion was approved by the General Assembly.

## RE: GENERAL PHENOMENA OF ADULT CRANIO-FACIAL BONE CHANGES

Ramfjord took exception to the statement, "Recent studies in white women over the age of 25 and up to the age of 90 years give clear evidence that the skeleton of the neural and visceral cranium continues to grow throughout life." Ramfjord stated, "I would like to hear the definition as used for growth versus remodeling and other growth processes in bone that are related to remodeling. It is a new concept to me that the mandible grows throughout lifetime." Atwood replied that studies conducted at the Fels Research Institute, and reported in the literature, would appear to substantiate this statement. *(Israel, 1967, 1968).*

## RE: GROSS MORPHOLOGIC CHANGES OF ALVEOLAR AND RESIDUAL BONE

Ramfjord questioned the statement, "There is some evidence that even if teeth are retained, the periosteal circumference, or superior-inferior height of the mandible decreases with aging." He felt certain that this is a result of periodontal disease and proposed that it be added to the record that this commonly occurs as a result of the presence of periodontal disease. Ramfjord added that there is no evidence to show that this occurs in a totally healthy mouth. Atwood cited the work of Israel *(1967)* to support the statement. Ramfjord asked whether the reference had been verified with regard to the presence or absence of periodontal disease in the subjects studied. Enlow replied that the reference in question was reported by Israel and that Israel had included a periodontal evaluation in the study. Enlow further stated that as he interpreted the reference, there was a decrease in the overall mandibular height with respect to the maxilla that may occur even in addition to the presence of periodontal disease.



Ramfjord replied, "Dr. Charles Williams did a number of studies in area in the early 1940's at a Chicago museum *(Williams, 1954)* and he not find any such changes in skulls which appeared to have been fr healthy individuals. I would like to have that reference added to minutes when published because the statement should not stand uncl lenged since it isn't true."

Perry asked for a reference to support the statement, "Incomplete d exists with respect to changes which occur when teeth are lost and dentures are worn. Available data and clinical observations suggest a les loss of residual bone in nondenture wearers than in denture weare: Atwood cited the work of Campbell *(1960)* and indicated that it wa cross-sectional, not a longitudinal study, and that further research \ needed.

## RE: HISTOLOGIC CHANGES IN EDENTULOUS ADULT MANDIBLE (RESIDUAL RIDGE)

Ryge asked if it was not established that cortical bone was more conc cive to the maintenance of the morphology of the particular locati of the jaw than was the alveolar bone or trabecular bone. Atwood co: mented that the section was unaware of any study which correlated t history (i.e., biopsies) of the bone with the rate of reduction.

## RE: CONTROL FACTORS

Zander stated, "I noticed that neither here nor anywhere else is the mention of a number of experiments that are in the literature whe ridges have been rebuilt, such as the studies by Boyne for instance, whe: he used bone marrow in some kind of a skeletal form to build a ne ridge. *(Boyne and Mikels, 1968; Yeager and Boyne, 1969).* It seems that througho this report, and also here, you discuss losses of residual ridge, but r place have you entered into the factors that allow us to build a ne ridge. Was this done intentionally?" Atwood commented that the sectic directed its attention to preservation of the residual bone and that rebuil ing ridges could well have been discussed along with a lot of other facto that were undoubtedly left out. In regard to the reference by Boyn Enlow stated that the concept of transplanting bone material to serv as an inductive stimulus was discussed by the section

## RE: CONCLUSION

The objections of the section to the term "alveolar bone" in the edentulous subject and preference for the term "residual bone" was discussed by the General Assembly. Ramfjord stated, "We cannot abolish the use of the term alveolar bone the way its defined, i.e., the bone which inserts the periodontal membrane and receives the pressures of the teeth. You can only clarify the uses and the differences between alveolar bone and alveolar process, but you cannot vote to abolish a well established term."

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SECTION II

# The Physiology of Jaw Movements

## Review of Literature

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## Section Report

## General Assembly Discussion

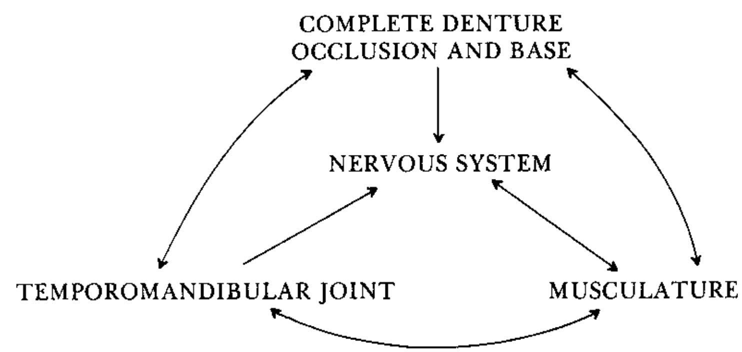
# REVIEW OF LITERATURE

*HANS GRAF*

For all aspects of dentistry, it is necessary to understand the relationship between the patterns of mandibular movements and occlusal form *(Ramfjord and Ash, 1971)*. Our knowledge of the biomechanics of functional and non-functional movements, however, is still inadequate. The gap of knowledge is particularly apparent regarding the relationship between neuromuscular function, mandibular movement, and occlusion of natural and artificial teeth *(Ahlgren, 1966)*.

A purely mechanical concept of the movements of the mandible is out of date, because it disregards the influence of the neuromuscular system. On the other hand, normal function and functional disturbances cannot be explained entirely on a neuromuscular basis *(Posselt, 1968)*.

In order to describe the biophysical interactions of the functional components of the masticatory system as related to complete denture occlusion, a simple diagram modified after Fröhlich *(1966)* may serve as a thinking model.




The three peripheral components are functioning in direct biomechanical relationships during movements of the mandible and the associated soft tissues. Each arrow indicates the influence of one component on the other that may be taken up for discussion using available clinical or experimental evidence.

The peripheral components provide the sources of information for the afferent input to the nervous system with its subcortical and cortical centers, in turn activating the musculature.

## BASIC CONCEPTS OF NEUROMUSCULAR PHYSIOLOGY

Jaw movements are brought about by the integrated activity of large portions of the nervous and muscular systems. In the cerebral cortex, functional activity is organized with outflow in the corticobulbar and corticospinal tracts to the major muscles involved in producing mandibular movements. From animal studies, jaw movements have been elicited from the motor cortex and a great number of subcortical brain centers, including the limbic system *(Schärer, 1970)*. A sensory flow back to the nervous system, probably indicating the position of all of the structures engaged in mandibular movements, was reported by Königsmark *(1970)*. This allowed other centers such as the cerebellum to project the necessary impulses for a smooth flow of motor activity. Current knowledge on neuronal circuitry has been reviewed with regard to mandibular movement in general *(Kawamura, 1968; Ramfjord and Ash, 1971)*, mastication *(Kawamura, 1946; Schärer, 1970)*, speech *(Königsmark, 1970)*, and deglutition *(Doty, 1968)*. It has recently been expressed in the conclusions of a review on the neuroanatomy of speech; "it is clear that, although much has been written about brain stem structures in animals, little is known about these structures in man" *(Königsmark, 1970)*.

The most recent theory of neuromotor activity *(Smith, K. V., 1961)* stated that, "sensory feedback organized in space and time dynamically links and controls the receptor and motor system of an organism. This control is accomplished at three levels; **a.** control of postural movements in relation to gravity, **b.** transport movements in relation to bilateral differences in stimulation; and **c.** manipulative movements in space." According to this formulation, any disturbance in the neurogeometric organization of motion may be expected to result in new patterns of perceptual-motor function *(Fletcher, 1970)*. Application of this theory to studies of mandibular movements in subjects with natural and complete denture occlusion might lead to a better understanding of sensory feedback mechanisms as well as improvement of therapeutic procedures.

It has been well documented that efferent neural systems are dependent upon afferent systems for appropriate function *(Hardy, J. C., 1970)*. For example, Houk and Hennemann stated that, "Complex movements require the participation of many types of feedback . . ." *(Hardy, J. C., 1970)*. They pointed out that sensory receptors in the skin of moving body members



seemed to be required for exploratory behavior and grasping, and that a large part of muscular activity in general seemed dependent upon visual information. Even though specific examples may be given for some types of activities, the integration of all afferent information that influenced any act is exceedingly complex *(Hardy, J. C., 1970)*.

Positive research findings that show the integration of afferent information necessary for efferent patterning are so numerous that a physiological separation of efferent and afferent mechanisms in the normally functioning human seemed untenable *(Hardy, J. C., 1970)*. Although sensory and motor systems may be identified anatomically, their interaction is so necessary for appropriate muscular patterning that physiologically they must be considered in terms of "sensory-motor systems."

From the neurophysiological standpoint three distinct systems have to be considered in studies concerned with sensory-motor functions *(Hardy, J. C., 1970)*.

*Reflex*—characterized by relatively direct visceral or somatic (skin, mucosa, muscle, tendon, etc., receptors) connections with peripheral efferent nerves.

*Tactile*—proprioceptive information transmitted to the cerebellum for coordination of muscle activity.

*Somesthetic*—somatic or visceral touch pressure systems and kinesthesia associated with conscious sensations and discriminative dimensions *(Mountcastle and Darian-Smith, 1968)*.

**MUSCLE RECEPTORS.** Although much more information is needed regarding the neuroanatomical mechanisms that transduce and transmit oral afferent information, it has been fairly well established that muscle spindles along with their afferent nerves are prime contributors to proprioception *(Hardy, J. C., 1970)*. There still is disagreement, however, about the existence of muscle spindles in tongue muscles *(Storey, 1967)*.

Proprioceptive control of the tongue muscle activity via the lingual and glossopharyngeal afferent nerves was suggested from findings in stimulation experiments by Kawamura, *et al.*, *(1967)*.

In view of the gamma loop mechanism, the primary afferent muscle spindles are considered as a potential compensatory mechanism capable of prediction of the length of the muscle after the reflex delay time *(Ringel, 1970)*, and thereby ensure that the response will correspond to the time when the reflex becomes effective rather than to the earlier time when the reflex was initiated *(Matthews, 1964)*.

**TEMPOROMANDIBULAR JOINT RECEPTORS.** It has been generally accepted that there are nervous receptors in the temporomandibular joints *(Kawamura, 1964; Ransjö and Thilander, 1963; Thilander, 1961, 1964)*. Their role in regulation and control of mandibular motor activity has been recently emphasized *(Kawamura, 1970; Osborne, 1969)*. The sensory mechanisms of the temporomandibular joints are hypothesized to play an active role in regulating the tension and length of jaw muscles, the position of the mandible, the maintenance of the "free-way space," and the dynamics of mandibular movements *(Kawamura, 1970)*. Clinical experimentation has indicated that temporomandibular joint receptors are involved in the perception of mandibular position *(Thilander, 1961)*.

**MUCOSA AND PERIOSTEUM RECEPTORS.** Apart from muscle and joint receptors, the cutaneous receptors in the oral mucosa may play an important role in the neuromuscular mechanisms of jaw movements. Grossman and Hattis *(1967)* summarized the variety and distribution of nerve endings in the mucosa of the gingiva, lip, buccal region, hard and soft palate, uvula, tongue and floor of the mouth. They agree with Gairns *(1956)* that many of these endings are basically the same in form, and state that a gross similarity existed in the pattern of innervation. They noted a declining progression of nerve-ending occurrence, generally from the front to the rear of the mouth, particularly in the tongue and hard palate. Lingual sensory terminations were more numerous on the dorsal than on the inferior aspects of the tongue.

Ringel *(1970)* discussed the mechanism of sensation in his review: Von Frey's *(1895)* classical concept of pain, cold, warmth, and touch could not be substantiated by Sinclair *(1955)*. The differences between the pattern theory and the specific receptor theory may be explained by Melzack and Walls *(1962)* proposal that, ". . . receptors are specialized physiologically for the transduction of particular kinds and ranges of stimuli into patterns of nerve impulses and that every discriminable different somesthetic perception is produced by a unique pattern of nerve impulses." This view has gained relatively widespread acceptance *(Ringel, 1970)*.

It seems clear that information from cutaneous receptors reaches a cortical level via the lemniscal system. Tactile information must contribute to conscious knowledge of kinesthesia *(Ringel, 1970)*. However, since functional jaw movements are highly automated motor acts, it is appropriate to ask whether these receptors are capable of contributing to reflex activity. Clinical observation *(Lammie, Perry and Crumm, 1959)*, tests with anesthesia of the oral mucosa *(Schaerer, Legault and Zander, 1966)*, and the work of Kawamura *(1970)* on the mandibular musculature, indicated that exteroceptive oral afferent impulses (pain) induced consciously or reflexly, spasms or increase muscle tonus. However, the exact role and relative importance of tactile stimuli from the oral mucosa in the control of jaw movements needed further clarification.

Another possible source of information for deep sensation of the face are the receptors in the mandibular and maxillary periosteum found in man in the form of free fiber endings *(Sakada, 1971)*. They may also play an important role in the sensory-motor system of mandibular movements in complete denture wearers.



## MUSCULATURE

The musculature of the oral or dentofacial complex associated with complete denture function may be divided into four groups on the basis of neural, functional, anatomical, and developmental differences. These muscle masses are highly interrelated, and there may be considerable overlaps in one or more of these criteria for classification *(Cox, 1970)*. The four muscle groups of the dentofacial complex include: (1) the muscles of mastication, (2) the intrinsic and extrinsic muscles of the tongue, (3) the muscles associated with the soft palate, and (4) the muscles of facial expression, principally those of the lips and cheeks. The physiology of jaw movements are such that these skeletal muscles are "programmed" to act in groups rather than as individual muscles. The gross anatomy can be obtained from a number of textbooks.

A detailed description of every muscle connected with complete denture construction was not deemed necessary. It is readily available from a number of relevant textbooks *(Boucher, C. O., 1970; Silverman, 1961; Wild, 1950)*.

**FUNCTIONAL ANATOMY.** It was not realistic to attribute a specific function to each of the mentioned muscle groups in view of the complex nature of functional and nonfunctional jaw movements *(Ramfjord and Ash, 1971)*. It would go beyond the purpose of this review to describe the anatomic features and major functions of each muscle. They have been treated in a number of textbooks and articles that contain further references *(Basmajian, 1967; Hickey, Stacy, and Rinear, 1957; Ramfjord and Ash, 1971; Roche, 1963)*. Most of these authors are concerned with dentulous patients, while others relate their descriptions to patients who wear dentures *(Silverman, 1961; Boucher, C. O., 1970)*.

The classical descriptions of mandibular movements in opening, closing, lateral, protrusion, and retrusion are based upon studies using methods such as anatomical dissection and electromyography. These are providing valuable information to serve as a framework for the understanding of the functional activity. They also are helpful for the examination of commanded control movements of the patient.

However, in order for complete dentures to be accepted and integrated in an optimal way by the edentulous patient, the functional muscular activity has to be understood. Mastication, deglutition, speech, and also rest, sleep, facial expression, and respiration are associated with mandibular movements. How movements associated with these activities are performed in the healthy individual with natural teeth, and also how complete dentures are being used as tools by the musculature for these functional tasks, is of great significance for therapeutic success.

## TEMPOROMANDIBULAR JOINTS

Numerous descriptions of the functions of the temporomandibular joints have evolved from anatomical studies and recordings by mechanical devices, photographic, and radiographic techniques, as well as other special methods *(Preiskel, 1970)*. The anatomic biomechanism responsible for condylar positions and movements are discussed frequently with regard to their significance for occlusal relations. With respect to centric relation for example, the muscular, the ligament, and the osteofiber theory have been confronted with the most recent meniscus theory by Saizar *(1971)*, stating that this position, "is determined by the fitting of the discs that acts on buffers and mufflers simultaneously between the condyles and the front parts of Glaser's fissure."

Normally, when the jaws are closed, the occlusal relationships between upper and lower teeth determine the position of the mandible against the maxillae and the relationships between the condyle, the disc, and the glenoid fossa. If the contacts are maintained between the upper and lower teeth, and gliding movements are performed, the contact relationship between the three components of the temporomandibular joint should be maintained *(Ramfjord and Ash, 1970)*. These movements could be termed occlusal border movements. Definitions of the normal static and dynamic anatomical relations emphasized that in maximal occlusal contacts, as well as in all movements guided by occlusal elements, the tissues in and around the temporomandibular joint space are neither traumatized by compression nor drawn apart *(Gerber, 1971)*. It seems logical that complete denture occlusion should aim to maintain or restore this basic physiologic relation.

Recent clinical experimentation on functional movements of the mandible have discussed the concept of a tooth-protected temporomandibular joint *(Gibbs, et al., 1971)*.

## KINESIOLOGY

The kinesiology of the mandible related to the maxillae during function has been described as extremely complex, since it commonly involves a combination of movements in the sagittal, frontal, and horizontal planes *(Ramfjord and Ash, 1970)*. In complete denture occlusion, the presence of two foreign bodies in the oral cavity replacing natural periodontal and occlusal



structures may alter mandibular movement patterns from the normal healthy individual. However, only a limited number of publications have been concerned with kinesiology of full denture patients, and *none* were found which compared mandibular movements before extraction and after the insertion of complete dentures in the same individual. However, a great number of studies have been reported on subjects with natural dentitions. Therefore, valid conclusions about complete denture occlusion as related to jaw movements are very limited.

**FUNCTIONAL AND NONFUNCTIONAL MOVEMENTS.** The Glossary of Prosthodontic Terms *(1968)* defined functional mandibular movements as:

1. All natural, proper, or characteristic movements of the mandible during speech, mastication, yawning, swallowing, and other associated movements.
2. Movements of the mandible which occur during mastication, swallowing, speech, and yawning.

Since the major functions of speech, mastication, etc., are specifically mentioned in these definitions, facial expression could be added as a function associated with mandibular movements.

Nonfunctional movements are *not* defined in the Glossary of Prosthodontic Terms *(1968)*. The following are suggested:

1. Control movements, such as voluntary (active), or guided (passive) excursions; for example, during diagnostic or therapeutic procedures (including border and nonborder movements).
2. Parafunctions *(Drum, 1950, 1958, 1962)*, which may be subdivided into occlusal (clenching, bruxism) and oral (tongue, lip, instrument playing, etc., habits) parafunctions.

Brill, *et al.* *(1959)* combined empty movements with functional movements. They suggested that nonfunctional movements include, "all occlusions other than those taking place in mastication or swallowing." They are differentiated into daytime and nighttime stress occlusions.

The committee report of the World Workshop in Periodontics *(Ramfjord, Kerr and Ash, 1966)* has defined occlusion as, "the contact relationship of teeth resulting from neuromuscular control of the masticatory system." This definition seems suitable for complete denture occlusion. The same Workshop defined occlusal trauma, or trauma from occlusion, as a lesion, that is, a pathologic state. This definition also seems applicable to complete denture occlusion. In addition to the cited examples of alterations concerning the tooth, the periodontium, the temporomandibular joint, and the neuromuscular system, changes of the denture supporting structures must be mentioned.

**MASTICATION.** According to Kawamura *(1964)*, and Pritchard *(1965)*, the complex neuromuscular activities of mastication involve biophysical and biochemical processes which include the use of the lips, teeth (dentures), cheeks, tongue, palate, and all other oral structures to prepare the food for swallowing. There are marked differences between patients with complete dentures and natural dentitions, including, **a.** the mucosal base instead of periodontal supporting structures, **b.** the progressive changes in maxillomandibular relations *(Tallgren, 1966)*, **c.** the migration of dentures *(Brigante, 1965)*, **d.** the sliding, lifting, and tilting of denture bases during function *(Sheppard, I. M., 1968)*, and **e.** the different physical stimuli to the sensory-motor systems. Yet certain characteristics of the masticatory stroke do not seem to be different *(Sheppard, I. M., 1971)*.

Edentulous patients seemed to preserve the basic masticatory cyclic movement similar to the ones found with subjects possessing natural dentitions *(Sheppard, I. M., 1967; Reumuth, 1957)*. Observations, such as the typical constant rate of chewing *(Kawamura, 1964; Briner, 1952)*, the fixed patterns as to the number of times a mouthful is chewed before swallowing *(Dahlberg, 1961)*, the so-called swallowing threshold *(Shiere and Manly, 1952)*, and the mandibular side shift *(Sheppard, I. M., 1967)*, may have their neurological explanation in an organizational area for mastication within the anterior portion of the lateral hypothalamic area, or within the subthalamic region *(Schärer, 1970)*. Previous neurophysiological theories on mastication considered these movements either completely cortically induced or entirely reflex controlled.

According to Hardy, J. C. *(1970)* the sensory-motor system influences the cyclic masticatory stroke pattern. This was related to the instantaneous energy requirement for trituration *(Briner, 1952; Fisch, 1953)* and reflex protection of all tissues involved.

**MASTICATORY PATTERNS.** A kinesiologic analysis of an Australian aboriginal girl with natural teeth lead Murphy *(1965)* to divide the natural masticatory stroke into six phases; the preparatory phase, contact with food bolus, crushing phase, tooth contact, grinding phase, and centric occlusion. A recognizable pattern emerged in this study in spite of a wide range of variation within the pattern. It confirmed the characteristic individual patterns of adult subjects with natural teeth found in earlier studies *(Hildebrand, 1931; Eberhard, 1947; Storey, 1967; Ahlgren, 1966)*.

Ahlgren *(1966)* compared his findings on children's masticatory patterns with a number of studies on adults. He inferred that although a patient with "normal" occlusion usually has a more regular chewing pattern than does a patient with malocclusion of the teeth, a direct relationship between movement patterns of the mandible in mastication and occlusion of teeth was not found. Many other factors, such as personality, temperament, social environment, and food selection are probably more decisive for the formation of the individual chewing pattern than the occlusion of the teeth.



Methods for studying mandibular movements have improved with the advancement of technology, from simple graphic records *(Carlsöö, 1956; Gysi, 1910; Hesse, 1900)*, to cinematography *(Syrop, 1953)*, and especially various applications of roentgenology. The first comprehensive studies of masticatory movements using cinematography and roentgenomography by Hildebrand *(1931)*, has been further reviewed in some 200 additional publications and the 600 works by 300 authors listed in Müller's *(1925)* book, *Grundlagen und Aufbau des Artikulationsproblems.*

From Hildebrand's time to the present, a number of motion studies have been published. The results of these investigations have varied greatly. Condyle movements, for example, have been shown to be first rotation and then translation *(Campion, 1905)*. According to other investigations *(Nevakari, 1956; Sheppard, I. M., 1959)* the opening movement was not a rotating hinge movement at all. Obvious irregularities in condylar movements have been shown by Berry *(1959)*. He described condylar movements as a zig-zag motion, partly due to the method of the investigation, and also to the interaction of several muscles as their action started and stopped, or increased and decreased. Opinions differed not only on *condylar* movements, but also on movements of the whole mandible.

It is obvious that measurements of mandibular movements on a point at, or near, the lower incisors, even in three dimensions, cannot provide information on the bodily movements of the mandible. Recordings of condylar movements alone cannot give the entire picture of mandibular movement patterns.

Changes of occlusal characteristics may influence the three-dimensional bodily movement pattern at one or the other, or at all sites, as theoretical and articulator studies have suggested. Three dimensional functional mandibular movements were first measured at three locations by Kurth *(1942)* using a graphical method. From this, and more recent studies *(Koivumaa, 1961; Messermann, 1967, 1969; Gibbs, et al., 1971)*, it became more clear that the typical motion of the working side condyle, the balancing side condyle, and the mandibular incisor point in all three dimensions, have to be considered simultaneously in order to better understand the role of occlusion.

From the results of these four studies on a total of approximately twenty normal subjects, an attempt has been made to summarize the typical average motion of three strategic sites of the mandible during the masticatory cycle (using the reports of the authors). During the *opening phase,* the incisor point moves downward, and towards the working side. The working condyle moves forward, downward, and slightly outward. The balancing side condyle moves with a greater excursion forward, downward, and inward. The change in direction at the incisor point for closing occurs in a continuous curved motion. Early in the *closing stroke,* the entire mandible moves more laterally. The working side condyle moves upward, backward, and medially and approaches its terminal position before tooth contact is reached. The working side condyle appears to be nearly stationary in the sagittal view for the remaining part of the closing stroke, but moves medially to its closed position. The balancing condyle moves upward, backward, and laterally to its closed position.

This extremely simplified, schematic description cannot take into account that the movements of the three selected mandibular points do not follow a definite, regular path. Considerable irregularities occur at the incisor point as well as in condylar movements from stroke to stroke. The mandible may be considered as a suspended body in space, held or guided by the anatomical tissue arrangement of the temporomandibular joints and is moved by the neuromuscular system. During the masticatory closing movement, occlusal morphology comes into play starting with "functional food contact" through to occlusal tooth contact.

The few studies considering complete denture patients *(Reumuth, 1957; Sheppard, I. M., 1967, 1968a, 1968b, 1971)* did not seem to indicate that mandibular movement patterns are significantly different from persons with natural teeth.

**SPEED.** Ahlgren *(1966)* has comprehensively reviewed the speed of masticatory movements. In this study on children, he found greater inter- and intraindividual variations in the speed of the masticatory movements. This was in contrast to the more constant form of movement patterns. "Form and speed of movements," he stated, "seem to be controlled by different neuromuscular mechanisms. Form of the masticatory movements is determined by an early conditioned reflex superimposed on a basic movement pattern and does not easily change. Speed of the masticatory movements on the other side is determined by the need of the occasion and, thus, easily influenced by physical and psychological variables." According to Ahlgren *(1966)* the more rapid opening phase *(Schweitzer, 1961; Sheppard, I. M., 1959)* appeared to be a ballistic type of movement with relaxed antagonists *(Carlsöö, 1956),* whereas the closing phase appeared to be a rapid tension movement with antagonistic control.

Ahlgren's *(1966)* measurements on variation of speed corroborates the earlier findings of Fisch *(1953),* Reumuth *(1957),* Sheppard *(1959a, 1959b),* and Ghiringhelli *(1961),* in that the mandible accelerated strongly during the beginning of the opening and closing movement and decelerated towards the turning point of the opening, and towards the end of the closing phase. With this decrease of speed, muscular tension development seemed to increase, producing the chewing force from "functional food contact" through to the possible occlusal tooth contact *(Briner, 1952).*



**FORCES.** In complete denture occlusion, this masticatory phase was associated with significant functional forces applied in the mouth *(Kurth, 1942).* It was apparent that the generation and disposition of the masticatory forces to the dentures, the food and all components of the masticatory system concerned are direct consequences of the direction, force, and rate of movement of the musculature as it activated the skeletal system.

Apart from alveolar profile conditions, muscular denture guidance and other retention factors, the stability of the denture largely depended upon the direction of the food force of mastication *(Ledley, 1954),* which in turn depended on three factors: **a.** the angle of motion during chewing; **b.** the characteristics of the food; and **c.** the placement and the morphology of the teeth in relation to the morphology and quality of the supporting ridges and the temporomandibular joints.

These theoretical considerations are well supported by clinical experiences. However, a number of the above stated relations remain largely untested. Direct measurements of the magnitude of forces, time and direction combined with mandibular motion, and tracking and recording of neuromuscular activity are needed to substantiate or evaluate the suggested relationships.

**TOOTH CONTACT.** That antagonistic tooth contacts do occur during mastication in subjects with natural and artificial teeth has been established by a number of telemetry studies. The functional range of contacts included occlusal gliding, both in the final closing and initial opening phase of the masticatory stroke, once the food has been chewed through. Despite great individual variations, and variations within the studied subjects, tooth contacts play a significant role during functional and nonfuctional movements. Feldmann *(1971)* has reviewed the recent studies on tooth contacts with artificial dentures, including the works of Yurkstas and Emmerson *(1954),* Brewer and Hudson *(1961),* Kaires *(1957, 1959),* Woelfel, Hickey and Allison *(1962)* and Neill *(1964, 1967).* The total number of subjects investigated in these studies was small and limited the conclusions that could be drawn. Another restriction for interpretation of the findings was the fact that accuracy of construction of the contacting areas measured was difficult to achieve. Occlusal contacts were recorded only in selected experimental contact areas. If, during mastication, no signals were recorded, contacts in other areas of the dentures cannot be excluded. All investigators found that tooth contact in complete dentures occurred during mastication on the chewing side. The frequency of contacts on the nonchewing side was greater than contacts on the chewing side. With regard to mandibular position, the dentures used in these studies were constructed so that the maximum intercuspation or planned contact was in centric relation or the terminal hinge position of the mandible. Other occlusal concepts, claiming other condylar or muscular positions as preferable for denture construction, have not been investigated for occlusal tooth contact patterns.

Occlusal tooth contacts do not give any information about direction or amount of force developed during their occurrence. Studies measuring tooth contacts only, not relating them to other parameters, are therefore limited in kinesiologic interpretation.

**SWALLOWING.** The physiology of swallowing has a long history of scientific and clinical interest. A review of selected topics on deglutition *(Weinberg, B., 1970)*, and mastication and deglutition *(Fletcher, 1970)*, covered this subject. Deglutition in relation to natural occlusion has been treated extensively by Ramfjord and Ash *(1971)*.

Throughout these reviews, the independent character of the swallowing reflex was emphasized. Once the act has been elicited, it runs its full course without significant proprioceptive modification or control *(Doty, 1968)*. On the other hand, it has been shown that electromyographic swallowing patterns may be influenced by changes of natural *(Ramfjord and Ash, 1971)* and complete denture occlusion *(Tallgren, 1961)*.

The regular, although not "compulsory," occurrence of tooth contact during swallowing, and cineradiographic observations of mandibular bracing against the maxillae in denture patients *(Sheppard, I. M., 1959a, 1959b)*, suggests that complete denture occlusion has to be compatible with, **a.** mandibular movements, **b.** the occlusal position achieved, and **c.** the forces during deglutition, in order to prevent occlusal trauma *(Ramfjord, Kerr and Ash, 1966)*. Whether swallowing can, or should, be used to determine the maxillomandibular relationship desirable for complete denture occlusion is questioned. Based upon cinephotographic observations on approximately 1000 subjects, Sheppard, I. M. *(1971)* concluded that swallowing can be used to obtain a reference position free of geometric implications. He introduced the functional term "bracing position."

**BORDER MOVEMENTS.** Posselt *(1952)* showed that border movements of the mandible of sixty-five healthy young individuals were reproducible and that all other movements took place within the framework of the border movements. The passively retruded position of the mandible was reproducible in the sagittal plane with a variation of 2.6 ± 0.8 mm. in twenty-nine subjects. Nyffenegger, Schärer and John *(1971)* confirmed this reproducibility in thirty young healthy individuals and concluded that the passive hinge movement had a constant and definite rotational and reproducible character. The amount of posterior border opening with pure rotation of the condyles has been determined by various authors *(Carlsöö, 1956; Fisher, 1939; Hardy, J. C., 1970; McCollum and Stuart, 1955; Posselt, 1952; and Ulrich, 1896)* and found to be between 10 and 30 mm.

The reproducibility of the posterior border path has gained wide acceptance in practical occlusal diagnostic as well as therapeutic procedures. However, whether the reproducibility of a mandibular border position can be used beyond the purpose of maxillomandibular spatial orientation is still controversial.



Since this reproducibility has been established in healthy young individuals only, it cannot necessarily be applied to older patients. Most edentulous persons have experienced a period with more or less destroyed natural dentitions, and in the course of this period, pathological changes of the temporomandibular joints may have taken place *(Posselt, 1952)*. Clinical, anatomical, radiographical, and histological examinations suggested that structural alterations in the temporomandibular joints may occur. The concepts of reproducible mandibular border movements may, therefore, not apply to the edentulous person.

**REST POSITION AND INTEROCCLUSAL SPACE.** Physiologic rest position of the mandible is presently defined in the Glossary of Prosthodontic Terms *(1968)* as, "the habitual postural position of the mandible when the patient is resting comfortably in the upright position and the condyles are in a neutral unstrained position in the glenoid fossae."

Ramfjord and Ash *(1971)* discussed the complex nature of the underlying neurophysiology of mandibular positions and the interactivity relationships between the various parts of the masticatory system and the central nervous system relative to the rest position of the mandible.

The concept of endogenously determined rest position *(Ballard, 1955)* being independent of the presence or absence of teeth and remaining stable throughout life *(Ulrich, 1896)* does not take into consideration a number of factors that may affect the resting position of the mandible. Murphy *(1967)* listed the factors as: **a.** the periodontal ligament receptors in the natural dentition, **b.** the pressure or tactile receptors in the mucous membrane investing the tongue, **c.** the ridges and lining of the lips and cheeks, which are stimulated by dentures in the edentulous mouth, **d.** the postural position of the tongue, **e.** the weight of mandibular teeth or lower dentures affecting position through gravity, **f.** the facial muscles and the relationships of the upper and lower lips, and **g.** the body posture and the emotional state of the person. In addition to these factors, Posselt *(1968)* includes sleep, age, occlusal changes, pain, muscle disease, temporomandibular joint disturbances, and systemic factors. Although many of these factors have not been subjected to controlled clinical experimental investigations, there seemed to be sufficient evidence from Atwood's *(1957)* cephalometric investigations, and Tallgren's *(1957, 1966)* longitudinal studies, that vertical dimension does not remain stable and can be altered.

A number of investigators have attempted to determine the "normal" or average amount of interocclusal distance that is present when the mandible is in rest position. It would appear that most of the studies attempting to make these determinations were undertaken for the purpose of aiding in the establishment of the "correct" interocclusal distance during extensive restorative procedures. The results of the studies of Niswonger *(1934)*, Posselt *(1952)*, Landa *(1952)*, Tallgren *(1957)*, and Garnick and Ramfjord *(1962)* can be summarized by stating that there was a great deal of variability in the amount of interocclusal distance between different patients, and a certain amount of variability within the same individual. The ranges seemed too broad and the averages too variable to recommend a correct or "normal" amount that should be restored in any patient. Ramfjord and Ash *(1971)* have pointed out that the interocclusal distance can be as wide as 8 to 10 mm. without being indicative of a disturbance of the function or health of the masticatory system, and therefore may qualify as biologically normal. They also warned against the application of average values to individual persons.

From this literature review it was apparent that our knowledge about complete denture occlusion and the physiology of jaw movements is quite incomplete and further controlled studies employing scientific methodology are imperative.

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# SECTION REPORT

## INTRODUCTION

Most of the evidence on physiology of jaw movements is based on studies of dentate individuals. Therefore, this report of the Physiology of Jaw Movements Section will be concerned with dentate as well as edentulous and edentoprosthetic individuals. Our statements take into account the biologic variation of the healthy "normal" state, but exclude disease unless otherwise specified. This Section was not concerned with definition of terms but relied upon the Glossary of Prosthetic Terms, Third Edition, with six exceptions. The following definitions were agreed upon for the operational use of the Section.

## DEFINITIONS

*Mandibular movements* are classified as masticatory and nonmasticatory movements. The nonmasticatory movements may be tooth contact or noncontact movements.

*Maximum intercuspation,* (centric occlusion). Maximum interdigitation of the teeth on closure of the jaws.

*Centric relation.* The relation of the mandible to the maxillae when the condyles are in the uppermost and rearmost position in the glenoid fossae. This position may not be recordable in the presence of dysfunction of the masticatory system.

*Centric relation contact.* The first contact of the teeth as the mandible is elevated in centric relation closure.

*Bennett movement.* The translatory movement of the mandible during its lateral excursions.

*Edentoprosthetic patient.* An edentulous patient wearing complete dentures.

*The questions submitted to this Section fell into the following categories:*

1. Regulation of Jaw Movements.



2. Factors that Modify Jaw Movements.
3. Recording of Mandibular Positions and Movements.
4. Special Questions.

## REGULATION OF JAW MOVEMENTS

The regulation of jaw movement depends upon structural elements, such as temporomandibular joints, ligaments, anatomy of the teeth, viscoelastic components of muscles, etc. These may be classified as passive components of the regulatory system. Regulation of jaw movement is also under neuromuscular or active control.

The pathways for impulses related to mandibular movement are under intensive investigation at this time and new data are altering present concepts so rapidly that the Section elects to make no statement on this point. The receptors for regulation of mandibular movements include periodontal ligament receptors, gingival receptors, bare nerve endings in the periosteum, Golgi tendon organs, muscle spindles and Golgi, Pacinian and Ruffinian endings in the temporomandibular joint. *(Kizior, Cuozzo and Bowman, 1968; Bernick and Levy, 1968; Jerge, 1963; Rapp, Kirstine and Avery, 1957).* Receptors in the periodontal ligament can initiate mandibular movement *(Thilander and Braxton, 1961; Anderson and Mahan, 1971)* and may modulate mandibular movement *(Schaerer, Stallard and Zander, 1967).* Loss of the periodontal sensory input in the edentulous patient would eliminate this potential source of control. Clinical impressions suggest that other sensory systems may compensate for loss of periodontal ligament receptors. This has not been documented.

Activation of neural systems leading to sensory perception (conscious level) should be differentiated from that of neural systems that serve as the sensory components of reflex arcs (reflex level). These two systems may be functionally discrete and independent. The practical implications of these two systems for full denture wearers need to be examined.

There is documentation that placing extremely thin material between opposing teeth in dentate and edentoprosthetic patients shows great difference in tactile thresholds between the two types of dentitions. The natural dentition shows much higher sensitivity than that demonstrated in complete denture patients *(Tryde, Frydenberg and Brill, 1962).*

In complete denture patients, a painful force (unconditioned stimulus) to the ridge mucosa underlying a denture base may result in cessation of jaw closure or in mandibular deviation (unconditioned response). Mechano-receptors in the oral mucosa, not normally initiating mandibular movements, could bring about mandibular deviation. Pressure (conditioned stimulus) transmitted to the ridge mucosa could bring about the same deviation (conditioned response) as a result of avoidance conditioning.

## FACTORS THAT MODIFY JAW MOVEMENTS

The movements of the mandible are limited in space as defined by Posselt *(1952)*. Mandibular movements in the edentoprosthetic patient are similar to those in the dentate subject. The only change in mandibular movement in the edentulous or edentoprosthetic patient from that of the dentate patient is at the superior or tooth-occluded border of the movement space. *(Woelfel, Hickey and Allison, 1962)*. The general shape of the masticatory cycle has been found to be similar in edentulous subjects to that of dentate subjects. *(Sheppard, I. M., Sheppard, S. M., and Rakoff, 1967)*. There is no evidence that age, as such, alters jaw movements. However, attrition of teeth with age will alter the tooth-contact movements of the mandible. *(Beyron, 1964)*.

Condylar movements are partially responsible for the movement pattern of the mandible. Condylar movement is not determined solely by the anatomy of the temporomandibular joint and muscle control. It can be influenced by changing occlusal guidance in the dentate subject. *(Preiskel, 1972)*. In complete denture patients, the lack of stability of the denture bases must mitigate the influence of occlusal guidance on condylar movements. It is possible that occlusal discrepancies in complete dentures can influence condylar movement through activity in the neuromuscular system. Scientific evidence for this influence of occlusal guidance upon condylar movement is lacking. A longitudinal study in progress at the University of Kentucky is evaluating muscle response, facial contour, tissue contour, subjective response and bone response to variations in construction of dentures. In one technique, the occlusion was balanced; in the other, it was not balanced.

Maximum intercuspation (centric occlusion) and centric relation contact are different anatomical positions in most patients with natural dentitions. *(Posselt, 1952; Beyron, 1964; Ingervall, 1964; and Hodge and Mahan, 1967)*. The distance between these two positions is subject to biologic variation. Clinical experience and opinion indicate that acceptable complete dentures can be constructed by providing for these two positions in their occlusion. Research is needed to document or refute this belief. The posterior occlusal border position is sometimes reached during swallowing, cleansing of the mouth and mastication. However, most tooth contacts occur within the borders. *(Graf and Zander, 1963; Adams and Zander, 1964; Pameijer, Glickman and Roeber, 1968; and Sheppard, I. M. and Sheppard, S. M., 1971)*. Border positions are used in nonmasticatory movements, such as those guided by the dentist in certain jaw registration procedures and possibly in bruxism. Citations to support this statement are well documented in the literature review of this Section.



## RECORDING OF MANDIBULAR POSITIONS AND MOVEMENTS

Examination of the stomatognathic system for state of health and correction of abnormal function may help insure that an accurate centric relation registration will be recorded in the edentulous patient. Correct recording and transferring of the transverse axis of rotation is critical if occlusal vertical dimension is to be changed on the articulator in complete denture construction. The axis of rotation can be accurately located and verified on an edentulous patient if the denture bases can be stabilized and the patient is free of pathological manifestations in the stomatognathic system.

It has not been shown that a position analogous to maximum intercuspation in the natural dentition can be recorded in the edentulous patient. Without tooth contact, there is no lasting neuromuscular memory to guide the mandible into such a position.

There is a question as to whether or not drugs may affect jaw registration. It has been shown that spasm of the masticatory muscles with displacement of the temporomandibular joint is a side effect of prochlorperazine [Compazine]. *(Kraak, 1967)*. Dentate patients on Compazine medication (e.g. ulcer patients) report that they perceive that their teeth do not occlude properly when they take the drug. It has also been shown that diazepam (Valium) and sodium salicylate alleviate the symptoms of myofacial pain-dysfunction significantly more than a placebo. *(Greene and Laskin, 1972)*. This therapy could therefore facilitate jaw registration.

Complete dentures are constructed on various types of articulators. The question can be asked whether functional movements of the mandible can be made to simulate those of the articulator. The human stomatognathic system is capable of adapting to occlusal function established on the articulator when movements on the articulator closely simulate those of the patient. If cuspal inclines established on the articulator interfere with each other during movements of the mandible, adaptation may not be possible. Patient comfort may be an important indicator of adaptation to articulator-established occlusal function. With the passage of time in the complete denture patient, the response of the supporting tissues and their state of maintenance must be considered in assessing this adaptability. Periodic reassessment of the occlusal function of the complete denture is essential. This concept of patient comfort is founded upon clinical observation and needs scientific documentation.

## SPECIAL QUESTIONS

The following questions posed to the Section did not lend themselves to narrative reporting and are presented in question and answer form.

**WHAT CHANGES IN THE ANATOMY AND FUNCTION OF THE TEMPOROMANDIBULAR JOINT ARE EVOKED BY THE COMPLETE LOSS OF TEETH?** There is evidence that loss of teeth *per se* does not result in changes in temporomandibular joint anatomy. *(Hedegård and Lundberg, 1965).* Cinefluorographic analysis of jaw function in complete denture patients indicates that no significant changes in function occur with loss of teeth. *(Remuth, 1957; Sheppard, I. M., Sheppard, S. M. and Rakoff, 1967; Sheppard, I. M., Rakoff and Sheppard, S. M., 1968; Sheppard, I. M. and Sheppard, S. M., 1968 and 1971).*

**WHAT EFFECT DOES AGE, LOSS OF POSTERIOR TEETH, MUSCLE TONUS AND PSYCHIC TENSION HAVE ON PHYSIOLOGIC REST POSITION?** Tallgren's review, *Changes in the Relationship of Complete Denture to the Supporting Tissues,* in the proceedings of this Workshop, discusses changes in rest position related to age and loss of posterior teeth. The significance of psychic tension on rest position needs to be investigated. Changes in muscle tonus detected by electromyography are not indicative of alteration in rest position.

**OF WHAT SIGNIFICANCE IS THE BENNETT MOVEMENT IN NORMAL FUNCTION? WHAT IMPLICATIONS DOES THE BENNETT MOVEMENT HAVE FOR COMPLETE DENTURE OCCLUSION?** In the natural and artificial dentition, the amount and character of the side-shift of the mandible may determine whether or not opposing cusps interfere during function. Bennett movement is important in establishing group function and balanced occlusion during occlusal reconstruction.

**WHAT IS THE RATIONALE FOR DISOCCLUSION OF THE POSTERIOR TEETH BY THE ANTERIOR TEETH IN ECCENTRIC POSITIONS?** There is no known rationale for such occlusal arrangement in complete dentures. Such an arrangement of anterior teeth predisposes to excessive stresses. The anterior arch tissues are already target areas for resorption and soft tissue lesions.

**CAN AN EXAMINATION OF JAW FUNCTION PROVIDE CLUES ON WHAT TOOTH FORM OR OCCLUSAL SCHEME TO USE IN A COMPLETE DENTURE?** Determination of the condylar guidance, incisal guidance, and inclination of the occlusal plane provide clues on what tooth form and/or occlusal scheme to use in a complete denture. Other factors, such as amount of residual ridge, soft tissue, state of health, etc., may modify the selection of teeth.



## SUGGESTIONS FOR RESEARCH

The deliberations of this Section reveal that there are several areas of ignorance and confusion based upon different clinical concepts. Therefore, research is necessary. Some of the questions which need answering are:

1. What is the most desirable jaw relation for developing occlusion for complete dentures?
2. Do occlusal discrepancies in complete dentures influence condylar movements?
3. Are pathways for neural control of mandibular movements different for edentoprosthetic patients than for dentate patients?
4. Which sensory systems compensate for loss of periodontal ligament receptors in patients with complete dentures?
5. What are the practical implications of activation of neural systems leading to sensory perception and activation of neural systems that serve in the reflex arc for the edentoprosthetic patient?
6. What is the role of mechano-receptors of the oral mucosa and periosteum in the regulation of mandibular movements in the edentoprosthetic patient?
7. Is the comfort of the patient a good criterion for evaluating complete denture treatment?
8. What is the effect of psychic tension on rest position of the mandible?
9. Are neuromuscular patterns of jaw movement retained after loss of the natural teeth? If so, how long?
10. Do post-insertion changes in complete denture patients affect mandibular movements?

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# DISCUSSION OF REPORT

Aull moved for acceptance of the Section report as read by Storey. The motion was seconded by Hickey and approved.

## RE: FACTORS THAT MODIFY JAW MOVEMENTS AND RECORDING OF MANDIBULAR POSITIONS AND MOVEMENTS

Celenza requested additional clarification regarding maximum intercuspation (centric occlusion) and centric relation when discussing the patient with teeth as opposed to the edentulous individual. Celenza cited two statements in the report for further comment. The first, "clinical experience and opinion indicate that acceptable complete dentures can be constructed providing for these two positions in their occlusion." Celenza felt that the implication in this statement was that there is a life long muscle memory to this centric occlusion position; while the widely accepted opinion is that this position is lost when the natural teeth along with their associated structures are lost. He also commented on the statement, "It has not been shown that a position analogous to maximum intercuspation [centric occlusion] in the natural dentition can be recorded in the edentulous patient. Without tooth contact, there is no lasting neuromuscular memory to guide the mandible into such a position." Celenza felt that once again the implication is that there still is such a position, and that there would be less confusion if it were indicated that an area be incorporated in the centric position, and not indicate that this is necessarily a mysterious muscle memory position. Storey responded by citing the research of Sheppard, I. M., Sheppard, S. M. and Rakoff, *(1967)*; Sheppard, I. M., Rakoff and Sheppard, S. M. *(1968)*; and Sheppard, I. M. and Sheppard, S. M. *(1968 and 1971)* as supporting documentation for these statements. Storey stated that the Section members felt that there is some evidence to suggest that this position, the equivalent of maximal intercuspation (centric occlusion), exists in the edentulous patient, but there are great difficulties in recording it.

Sheppard commented that when given complete freedom of choice, the preferential location of closure appears to be the swallowing position, but there is no constancy of any of these points of closure. He found in his studies that about 60% of the closures occurred in the swallowing position and it was the most constant of the closing positions found. Unsatisfied that this answered his question, Celenza said that he agreed that there was another position, but there is no evidence to indicate that that position is coincident with the position that once existed when the teeth, the periodontal ligaments, and the associated neuro-structures were present. Hickey pointed out that it was the feeling of the Section members that the position of maximum intercuspation (centric occlusion) of the dentate patient could not be registered with any degree of accuracy when the patient became edentulous; the memory pattern would not continue over into the edentulous patient. The Section members felt that in the construction phase of dentures, if centric relation position was used to establish the intercuspation of the teeth, then some procedure should be used so that the teeth would contact evenly, forward of this position. If, on the other hand, a position was utilized to establish the occlusion that was forward of centric relation, some mechanism should be used to provide for even contacts of teeth in the most retruded position and that an acceptable occlusion could be developed by either method. Isaacson asked, "What methodology would there be to check on the retruded position once you have established an anterior position on an articulator?" Hickey replied that this was a serious problem so far as his own procedures would be concerned. However, there are those who feel that this can be adequately done as an intra-oral procedure.

Continuing to answer Celenza's question, Hickey said that there is still another group, of a significant large size, which feels that some position anterior to centric relation should be established which is under the patient's control with no concern for the centric relation position. The Section felt that research is necessary in this area. Celenza further stated that his concern was in calling this anterior position "centric occlusion," that in some way related to the centric occlusal position that existed when teeth were present. Zander commented that this area of discussion was very difficult for their Section because the opposite of this, namely that centric relation contact and the position of maximum intercuspation (centric occlusion) must, in denture wearers, always be one and the same position, was not acceptable to the Section members and this is the closest that the members thought they could come to explain what they meant.

## RE: SPECIAL QUESTIONS

Dale Smith asked if the statement, "Determination of the condylar guidance, incisal guidance, and inclination of the occlusal plane provide



clues on what tooth form and/or occlusal scheme to use in a complete denture," presumes that balanced occlusion is a requirement, a fact which he did not think had been shown. Aull replied that nothing in the statement assumes that the Section was thinking entirely about balanced occlusion. He said that condylar guidance and incisal guidance are set on the instrument and we must determine the inclination of the occlusal plane, an arbitrary thing. This should not preclude using a certain type of tooth. Dale Smith continued, "If you presume that balanced occlusion is not a necessity, then I don't think condylar guidance, incisal guidance, or inclination of the occlusal plane really have anything to do with selection of tooth form." Aull answered by stating that if you are going to use a cusp tooth as your choice, these factors should help you in your selection of cusp angle.

Yurkstas asked how one would examine the jaw functions in the edentulous patient? Aull replied that one could not determine any of these things until models are mounted on the instrument and the proper records obtained for setting the instrument. Then one can analyze the movements.

Celenza commented that the statement, "In the natural and artificial dentition, the amount and character of the side-shift of the mandible may determine whether or not opposing cusp interfere during function. Bennett movement is important in establishing group function and balanced occlusion during occlusal reconstruction." He felt that centric occlusion should also be included because lack of interference during the exit and approach to and from centric occlusion can be affected by the amount and degree of the side-shift, the character of the side-shift, and also the character of the centric position. In addition, condylar path factors can influence even zero degree teeth.

Woelfel objected to the statement, "changes in muscle tonus detected by electromyography are not indicative of alterations in rest position." He felt that based on fifteen years experience in using both clinical observation and electromyography to determine rest position, that the phrase "electromyography is not indicative" be changed to "may not be indicative," or even, "may indicate a change in rest position." Woelfel said that electromyography will not infallibly indicate rest position. Storey replied that one has to look at another means of determining where the mandible is located in space and that electromyography alone cannot give you that information.

Wictorin commented that studies by Hedegård and Wictorin *(1968)* indicate that there is a change in function with loss of teeth, particularly during mastication, which would not support the statement, "cinefluorographic analysis of jaw function in complete denture patients indicates that no significant changes in function occur with loss of teeth."

## RE: SUGGESTIONS FOR RESEARCH

Woelfel questioned the advisability of further research related to the statement, "Is the comfort of the patient a good criteria for evaluating complete denture treatment?" Woelfel stated that research has shown that the patient is not a reliable guide as to how satisfactory the dentures are after a period of time, and further research to document patient's reliability seems unnecessary.

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SECTION III

# Articulators and Articulation

## Review of Literature

### Articulators and Determinants of Occlusal Morphology

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### Transfer of Maxillomandibular Relationships to the Articulator

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Occlusion as Related to Complete Removable Prosthodontics

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Section Report

General Assembly Discussion

# REVIEW OF LITERATURE
## Articulators and Determinants of Occlusal Morphology

*FRANK V. CELENZA*

## *ARTICULATORS*

From a review of the literature on articulating devices, several things become apparent. First, to merely list all of the instruments would be of little value. Second, a great deal of duplication of effort by instrument designers was observed. Finally, a classification that would organize these instruments as to their usage was not apparent.

## HISTORY OF ARTICULATORS

This review will survey the literature for historical interest, for originality of design, and suggest a classification based on function.

In the fabrication of any dental prosthesis, a mechanical holding device must be used when relating opposing models. We call this device an articulator. In the Glossary of Prosthodontic Terms *(1968)*, an articulator is defined as "a mechanical device which represents the temporomandibular joints and jaw members, to which maxillary and mandibular casts may be attached." There are many devices which are called articulators that do not satisfy the definition. Some of these devices do not attempt to represent temporomandibular joint motion, claiming that the center of motion is elsewhere. Others, such as the plain line instruments, make no claim for duplication of eccentric motion. Yet the profession, as well as the designers and inventors, refers to all of these instruments as articulators.

Many instruments are constructed for various procedures and do not seem to satisfy the above definition. For purposes of reviewing instruments, the following classification of *cast relators* will be used. The basis of the classification is on instrument capability, intent, registration procedure, and registration acceptance.

## CLASSIFICATION OF CAST RELATORS

**CLASS I.**—Simple holding instruments capable of accepting a single static registration. Vertical motion is possible, but only for convenience.

**CLASS II.**—Instruments that permit horizontal as well as vertical motion but do not orient the motion to the temporomandibular joint.

*Subdivision A.* Eccentric motion permitted is unrelated to patient motion.

*Subdivision B.* Eccentric motion permitted is based on theories of arbitrary motion.

*Subdivision C.* Eccentric motion permitted is determined by the patient, using engraving methods.

**CLASS III.**—Instruments that simulate condylar pathways by using averages or mechanical equivalents for all or part of the motion. These instruments allow for joint orientation of the casts and may be arcon or nonarcon instruments.*

*Subdivision A.* Instruments that accept static protrusive registrations and use equivalents for the rest of the motion.

*Subdivision B.* Instruments that accept static lateral protrusive registrations and use equivalents for the rest of the motion.

**CLASS IV.**—Instruments that will accept three dimensional dynamic registrations. These instruments allow for joint orientation of the casts.

*Subdivision A.* The cams representing the condylar paths are formed by registrations engraved by the patient. These instruments do not allow for discriminatory capability.

*Subdivision B.* Instruments that have condylar paths that can be angled and customized either by selection from a variety of curvatures, by modification, or both.

## INSTRUMENTS OF HISTORICAL SIGNIFICANCE

**CLASS I CAST RELATORS.** The first cast relator was formed by extending the rear portion of the upper and lower casts in plaster of Paris. The casts were keyed together with a groove, notch or circular depression in the registered position. This was called a *plaster occludator.*

J. B. Gariot (1805) was credited with having invented the first instrument to serve as a cast relator. The instrument used a screw against a plate to serve as a vertical stop in the rear of the cast relator.

*Arcon is a word coined by Bergström *(1950)* that describes instruments which have guiding paths situated in the upper member and axial centers in the lower member. It is a contraction of two words; ARticulator-CONdyle. Those instruments that have the controls in reverse had been called condylar instruments. It seemed less confusing to call these latter instruments nonarcon types.



The Stevens was similar in design, and in addition featured an incisal pin and table instead of the vertical stop in the rear. Both were hinged instruments.

The Fournet (1935) instrument possessed a vertical sliding movement, perpendicular to the horizontal plane, as well as a hinged movement. Abrasive wheels and a rotary crank were supplied to "mill-in" the occlusion. The casts were arbitrarily mounted with the bite rims parallel to the base of the instrument frame.

**CLASS II CAST RELATORS, SUBDIVISION A.** The Evans (1840) instrument provided slots for lateral movement on each side with the center of rotation for lateral motion in the center of the instrument frame.

The Starr (1868) also had slots for lateral movement on each side parallel to the bows of the instrument. The centers of lateral rotation were contained in each slot.

The Hayes (1889) instrument provided paths which were inclined for an angled protrusive movement. The first face-bow, called the Hayes Clipper, was used with this instrument. Orientation to the joint was only in the anteroposterior direction.

Bixby (1894) designed a bite fork attachment which could be fastened to plain line instruments, thus fixing the anteroposterior distance of the casts to the joint. This was a forerunner of today's face-bow.

Walker (1895) designed his instrument with adjustable paths which were set by an extraoral measuring device called Walker's Facial Clinometer. The casts were oriented to the instrument according to Bonwill's Triangle.

Grittman (1899) designed an instrument with condylar paths inclined at 15°. It was an arcon instrument and utilized Bonwill's principles for orientation.

Christensen *(1901)* was the first to recognize the inclination of the condylar path and the importance of registering this angle. His arcon instrument allowed for adjustment of the condylar path inclination by setting to an anterior checkbite registration. The later addition of the Snow face-bow orientation enabled this instrument to be placed in Class III, Subdivision A.

The Kerr brothers (1902) designed an instrument similar to Grittman's except that they added the feature of adjustment selection to the condylar guidance.

Gysi (1914) designed the Simplex instrument which probably was the most advanced of this group. This instrument was designed to adjust to average angles as determined experimentally by Gysi. While the numerical values have been challenged, the principle of relating patient motion to the instrument was accepted. It was an arcon instrument with a fixed condylar path of 30°, a fixed intercenter distance, an incisal guidance of 60°, a symphyseal angle of 120°, and a Bennett angle of 15°. This instrument is included in this group because of the fixed condylar pathway.

**CLASS II CAST RELATORS, SUBDIVISION B.** Bonwill (1858) constructed an instrument based on observations that a four inch equilateral triangle defined the distances between the condyles, and the condyles and the symphysis. The instrument permitted anteroposterior movement.

Schwarze (1900) designed an instrument similar to Bonwill's with the addition of superior-inferior motion.

Monson (1920) postulated that the center of all mandibular motion was located in the center of a sphere with a four inch radius. The vertices of Bonwill's Triangle touched the perimeter of the sphere. The instrument had two shafts going through the center. Although his theory was called the spherical theory, the motion permitted was not purely spherical. Monson also believed that the motion was influenced by an axis passing through both condyles. He positioned a third shaft in this position.

Tinker (1931) designed an instrument similar to Monson's except that he eliminated the condylar shaft, thus allowing pure spherical movement.

Hall (1916) designed several instruments with various concepts. The most interesting of these was an instrument which provided for multiple placement of the lower cast with each eccentric registration (1934). Rubber packings in the joints of the instrument allowed for movement around each position. The connecting pathways were either determined by the instrument or adjusted directly on the patient.

**CLASS II CAST RELATORS, SUBDIVISION C.** Warnekros (1892), Eichetopf (1914), Wustrow (1925) and Schybergson (1950) designed instruments which could be adjusted to generated pathways on bite rims. They used abrasives or cutters to accomplish this and recommended these instruments for full denture prosthesis.

House (1940) used the same principle and added a rotary grinder to the instrument which allowed for milling-in of an area of centric occlusion. The casts were arbitrarily mounted, but the dimensions of the instrument satisfied Bonwill's principles.

Smith (1969) called his instrument the Gnathic Relator. It was a jig which related a three-dimensional engraved recording taken at the occlusal level to the master casts. It was a jointless device.

**CLASS III CAST RELATORS, SUBDIVISION A.** Christensen *(1901)*. (See Class II, Subdivision A.)

Snow's (1906) New Century instrument was an arcon type with adjustable condylar paths. It was designed to accept a face-bow mounting. The face-bow was invented by Snow in 1899.

The Wadsworth (1919) had adjustable condylar posts set to the anatomic position of the patient according to the width of the face-bow calipers. It also had curved paths which could be adjusted and was a nonarcon type instrument.

The Hanau (1927) Model H was similar in design to the Wadsworth. It was the first of a series of instruments by the designer and it provided for a face-bow mounting, a static protrusive registration, and a limited adjustment (up to 20°) for the Bennett angle. It was a nonarcon type. The Bennett angle was determined by the formula $H/8 + 12$, where H was the inclination of the condylar path. The derivation of the formula has never been explained or justified.

The Dentatus (1944) was similar in design to the Hanau and had several added features, including longer condylar posts, Bennett angle adjustment up to 40°, extendible condylar axis pins (acceptance of kinematic axis location) and orbital plane transfer.

Bergström *(1950)* designed an instrument called the Arcon. It had all the features of the Hanau Model H in addition to its being an arcon type instrument.

Gerber *(1959, 1971)* designed the Condylator, an instrument which accepts a face-bow. The joint mechanism provides for individual setting of the protrusive condylar path. The average superior condylar surface is reproduced for a three-dimensional Bennett movement. A retrusive path from centric occlusion to the most retruded position (back and down) is provided. The Condylator (Vario, 1970), is equipped with adjustments for opening-compressed or closing-distracted joint spaces.

**CLASS III CAST RELATORS, SUBDIVISION B.** Instruments in this group are capable of accepting most static lateral protrusive registrations. The adjustments are necessary for intercenter distance, Bennett angle, and Fisher angle accommodations. Not all of these instruments provided for all of these adjustments.

Davis and Lenchenring (1905) were the first to provide for an adjustable intercenter distance. This added feature was also used by Anderson (1912), Aspelund (1912), Hall (1917), Lentz (1925), Hanau Kinescope (1923), and Brandrup-Wognesen (1936). All of these instruments were constructed to follow Gysi's main concepts. Anderson, however, considered the arcon arrangement essential and took issue with Gysi on this point.

The Gysi Adaptable (1908) was a very advanced instrument for its time. Extraoral graphic registrations were used for setting the sagittal condylar guides. The intercenter distance was set according to the gothic arch tracing. The graphic registration was according to Gysi's design.

Eltner (1909) was the first to design a face-bow that became the cast relator when removed from the patient. He proposed the idea that there were two horizontal axes, one through the condyles and one through the eminences. His instrument was set to graphic registrations according to Gysi's concepts. Neither the Gysi Adaptable, nor the Eltner, could be adjusted to three-dimensional graphic registrations as we know them today. Equivalents dictated by the instrument design supplied the missing portions of the motion and therefore are placed in Class III, Subdivision B.

The Gysi Trubyte (1926) was a nonarcon type that provided for a face-bow, condylar path adjustment, and Bennett angle adjustment by means of guides in the center of the upper bow. This enabled the instrument to accept some lateral registrations. The intercenter distance was fixed.

Stansbery (1932) constructed a jig he called the Tripod. It allowed for adjustment to static eccentric registrations. The instrument was later provided with a face-bow and a rotary grinder.

Phillips (1937) designed the Occlusoscope which was a checkbite instrument. He introduced the central bearing device to the profession in 1927.

The McCollum Check Bite (1951) instrument accepted a kinematic axis transfer, had adjustable condylar paths, Bennett guides, and intercenter distance.

The Transograph (1952) designed by Page was an instrument based on the concept that there are two horizontal axes (one for each condyle) and that the vertical and sagittal axes do not intersect with the horizontal axes, nor do they intersect with each other. The flexibility of the instrument allowed for vertical and lateral motion. The technique called for eccentric positional registrations of varying distances on the lateral path, a kinematic location of the horizontal axis, and centric relation registrations of varying thicknesses.

The Spence (1958) instrument had the same features as the McCollum checkbite cast relator.

The De Pietro Ney (1960) checkbite instrument accepted a kinematic face-bow and was the first instrument to combine the rear wall, medial wall, and superior wall of the condylar path into one assembly. The condylar path assembly could be tilted in all three planes and the instrument had an adjustable intercenter distance.

The Whip Mix articulator, designed by Stuart (1962), receives the arbitrary face-bow and has three positions for intercenter distance adjustments (small, medium and large) according to facial width. It has a combined condylar pathway, similar to the Ney, with a separate adjustment for the medial wall to accommodate the Bennett angle.

The Hanau University Model 130-21 is one of the most advanced of the Hanau University series. It has the following features: axis-orbital transfer, adjustable condyle path inclination, sagittal tilt and vertical rotation, adjustable Bennett guides, and adjustable intercenter distance. It is an arcon instrument but none of the condylar paths can be customized.

The Granger Simulator allows for the setting of the Bennett angle by adjustment only. It permits adjustment of the condylar path in all three planes, it has adjustable rotational centers, kinematic axis, orbital plane transfer, and can be supplied with a variety of condylar paths.



**CLASS IV CAST RELATORS, SUBDIVISION A.** Luce (1910) designed an instrument that combined joint orientation with an engraving method. The casts were oriented to the instrument by means of a face-bow. Occlusion rims with generated path registrations served as guides for forming the cams of the instrument. A "well-like" receptacle in the rear of the lower frame of the instrument was centrally placed and another was located at the position of the incisal table. These receptacles would receive a material (modeling plastic) that would register the record against an incisal pin in front, and four studs in the rear of the upper frame. The shaft representing the horizontal axis was removable to allow for eccentric motion. It was a nonarcon instrument.

The Hagman Balancer (1925) was an instrument similar in concept to Monson's, with some added features. Hagman advocated a kinematic axis transfer with an orbital pointer. He supplied a universal joint in the center of the sphere and provided a cup at the incisal table to register a generated path record. Since this acted as the cam of the instrument, it was classified as a nonarcon type.

The TMJ instrument, designed by Swanson and Wipf (1965), is an arcon instrument with cams placed in the approximate area of the centers of the condyles by means of a kinematic axis transfer. Average distances from the skin point are used (12 mm.) to locate the centers of lateral rotation. The cams are molded in plastic from a registration generated intraorally by three scribers against a recording material.

Lee (1969) designed an instrument similar in concept to the TMJ instrument except that the cams are formed by air-rotor directly on the patient and are transferred to the frame of the upper bow by means of a kinematic face-bow. It is an arcon instrument.

**CLASS IV CAST RELATORS, SUBDIVISION B.** The instruments in this group accept a kinematic axis transfer, have condylar paths adjustable in three planes, Bennett guide adjustments which can be customized, adjustable intercenter distance, plane of reference transfer, and are of the arcon type.

The McCollum Gnathoscope (1930) and the Granger Gnatholator (1955) are full-tracking instruments with a variety of metallic condylar paths with different radii.

The Guichet Denar (1966) is a half-tracking instrument with a selection of plastic condylar paths which can be chosen according to the proper radius, and further customized by altering the insert. It has two adjustments of the medial wall (angulation and straight displacement) and a separable rear wall which can be adjusted.

The Stuart Gnathoscope (1955) is a nontracking instrument with a variety of plastic paths to choose from, which can be further customized by alteration. The Bennett guides are separate from the roof of the condylar path and can be angulated and customized in contact with fixed spheres which maintain the centric position.

## REQUIREMENTS OF AN ARTICULATOR

If we consider an articulator according to the definition, then we should set down some standards or requirements that will satisfy the definition. If an articulator represents the temporomandibular joint, then only those that permit an orientation of the casts to the joint by means of a face-bow can be called articulators. This is a minimum requirement. If the motion of the joint is also to be represented, then some sort of eccentric motion should be recorded and transferred to the articulator. The articulator should be capable of accepting the eccentric registration.

The temporomandibular joint is one of the parts of the system that influences the pathways of travel of the condyle assembly (condyle, synovial cavity and articular disc). It is incorrect for us to consider the motion within the temporomandibular joint a bone-to-bone movement. The condylar path is influenced by the joint, the ligaments, the neuromuscular complex, and when teeth are present and in contact, the occlusal configuration of the contacting surfaces. The motion that is permitted by this system is a combination of rotation and translation. In order to duplicate the condylar path, this complex combination must be resolved by recording and adjustment procedures and then be recombined to follow the path. It is possible to accomplish this task if extreme (or border) movements are recorded.

There are basically seven requirements of an ideal articulator. These are:

1. The instrument should accept a horizontal axis transfer. This will enable the operator to maintain centric relation with changes in vertical dimension. The horizontal axis orients the casts to the temporomandibular joint and thus all motion recorded to it. The horizontal axis may be arbitrarily located (by average measurements, landmarks, or palpation) or preferably kinematically located.
2. The articulator should be equipped with an adjustable intercenter distance. The importance of duplicating the correct position of the rotational centers has been pointed out by Anderson, McCollum, Beck, and others. This facility is mandatory for duplication of lateral registrations.



3. In order to correctly set the inclination (in all three planes), and character of the condyle path, the articulator must have the capacity for complete three-dimensional adjustment of the condylar path, and still more desirable, complete customization. This can be done by interchangeable paths of various radii or customizing plastic cams. In order to maintain the condylar path constant to the plane of occlusion when changing the vertical dimension, the instrument must be of the arcon type. Therefore, the cams must be on the upper member and the axial centers on the lower.
4. Displacements in the horizontal plane that are translatory must be reproduced by the articulator, or the lateral pathways cannot be duplicated. The instrument, therefore, must have adjustable Bennett guides that enable it to follow both pure translatory movements (immediate side shift) and combinations of rotation and translation (progressive side shift). These guides should be contained in the upper bow.
5. In order to assign numerical values to recorded motions so that the articulator can be reset for each mounting procedure, the instrument must have provision for acceptance of a plane of reference in the upper member.
6. Since there are times when the exact motion recorded is not the most desirable motion to use in the occlusal scheme, the instrument should be capable of alterations. Guichet calls this "discriminatory capability." This enables the operator to decrease angles he feels are in excess, to the needs of the patient. This feature is automatic in instruments that are adjustable. Instruments that form their cams from engraved registrations do not have this capability.
7. The most important requirement of an articulator is that it maintain a centric positon. In the type of instruments described thus far, this is largely a problem of machinery. Loss of centric position is a greater possibility in a full-tracking instrument than in a nontracking instrument. If the engraving and machining is inaccurate, adjustments in the intercenter distance will create a loss of the centric position which will be much more noticeable in the full-tracking instruments. This is because the upper and lower members are in a fixed relation to each other by means of the track of the condylar path. The inaccuracy causes binding, and the resulting flexion of the instrument causes an inaccurate centric position. The half-tracking instruments have this problem also, but to a lesser degree.

**CONVENIENCE FACTORS IN DESIGN.** Articulators should be of rigid construction with a minimum number of metal-to-metal parts. They should be comfortable to handle and easily separated to facilitate fabricaseparable rear wall which can be adjusted.

The Stuart Gnathoscope (1955) is a nontracking instrument with a variety of plastic paths to choose from, which can be further customized by alteration. The Bennett guides are separate from the roof of the condylar path and can be angulated and customized in contact with fixed spheres which maintain the centric position.

## REQUIREMENTS OF AN ARTICULATOR

If we consider an articulator according to the definition, then we should set down some standards or requirements that will satisfy the definition. If an articulator represents the temporomandibular joint, then only those that permit an orientation of the casts to the joint by means of a face-bow can be called articulators. This is a minimum requirement. If the motion of the joint is also to be represented, then some sort of eccentric motion should be recorded and transferred to the articulator. The articulator should be capable of accepting the eccentric registration.

The temporomandibular joint is one of the parts of the system that influences the pathways of travel of the condyle assembly (condyle, synovial cavity and articular disc). It is incorrect for us to consider the motion within the temporomandibular joint a bone-to-bone movement. The condylar path is influenced by the joint, the ligaments, the neuromuscular complex, and when teeth are present and in contact, the occlusal configuration of the contacting surfaces. The motion that is permitted by this system is a combination of rotation and translation. In order to duplicate the condylar path, this complex combination must be resolved by recording and adjustment procedures and then be recombined to follow the path. It is possible to accomplish this task if extreme (or border) movements are recorded.

There are basically seven requirements of an ideal articulator. These are:

1. The instrument should accept a horizontal axis transfer. This will enable the operator to maintain centric relation with changes in vertical dimension. The horizontal axis orients the casts to the temporomandibular joint and thus all motion recorded to it. The horizontal axis may be arbitrarily located (by average measurements, landmarks, or palpation) or preferably kinematically located.

2. The articulator should be equipped with an adjustable intercenter distance. The importance of duplicating the correct position of the rotational centers has been pointed out by Anderson, McCollum, Beck, and others. This facility is mandatory for duplication of lateral registrations.



3. In order to correctly set the inclination (in all three planes), and character of the condyle path, the articulator must have the capacity for complete three-dimensional adjustment of the condylar path, and still more desirable, complete customization. This can be done by interchangeable paths of various radii or customizing plastic cams. In order to maintain the condylar path constant to the plane of occlusion when changing the vertical dimension, the instrument must be of the arcon type. Therefore, the cams must be on the upper *member* and *the* axial centers on the lower.

4. Displacements in the horizontal plane that are translatory must be reproduced by the articulator, or the lateral pathways cannot be duplicated. The instrument, therefore, must have adjustable Bennett guides that enable it to follow both pure translatory movements (immediate side shift) and combinations of rotation and translation (progressive side shift). These guides should be contained in the upper bow.

5. In order to assign numerical values to recorded motions so that the articulator can be reset for each mounting procedure, *the instrument* must have provision for acceptance of a plane of reference in the upper member.

6. Since there are times when the exact motion recorded is not the most desirable motion to use in the occlusal scheme, the instrument should be capable of alterations. Guichet calls this "discriminatory capability." This enables the operator to decrease angles he feels are in excess, to the needs of the patient. This feature is automatic in instruments that are adjustable. Instruments that form their cams from engraved registrations do not have this capability.

7. The most important requirement of an articulator is that it maintain a centric positon. In the type of instruments described thus far, this is largely a problem of machinery. Loss of centric position is a greater possibility in a full-tracking instrument than in a nontracking instrument. If the engraving and machining is inaccurate, adjustments in the intercenter distance will create a loss of the centric position which will be much more noticeable in the full-tracking instruments. This is because the upper and lower members are in a fixed relation to each other by means of the track of the condylar path. The inaccuracy causes binding, and the resulting flexion of the instrument causes an *inaccurate centric* position. The half-tracking instruments have this problem also, but to a lesser degree.

**CONVENIENCE FACTORS IN DESIGN.** Articulators should be of rigid construction with a minimum number of metal-to-metal parts. They should be comfortable to handle and easily separated to facilitate fabrication and refinement of prostheses. It is much more convenient to have separable bows, rather than those that cannot be separated. Mounting procedures should be simplified. Several instruments have devised techniques in mounting that eliminate the mounting frame. If there is an immediate translatory motion from the centric position on both sides, it is difficult to work with both adjustments engaged and still maintain the position. A spring latch return is helpful in these situations and is supplied with some of the more advanced instruments of this type. Fully adjustable incisal guide tables are very convenient and should be included in these articulators. This is preferable to the plastic guide which can be customized.

## *ARTICULATION*

The masticatory apparatus is capable of pathways of motion that are both varied and geometrically complex. This motion can be analyzed to determine the character of the borders and the limits of the pathways of movement. The border pathways have been described by Posselt (1962) as being ligamentously limited and neuromuscularly powered. Further emphasis on the neuromuscular input has been expressed by Boucher, L. and Jacoby *(1961)*. The pathways have been considered replicable by several investigators *(Posselt, 1962; McCollum, 1955; Stuart, 1959; Balkwill, 1866; and Bonwill, 1899)*. Grasso and Sharry *(1968)*, in a study of replicability of arrow-point tracings, found the greatest anteroposterior variation in the position of the apex to be only 0.42 mm., while the greatest mediolateral variation was 1.90 mm. The range anteroposteriorly has also been reported as 0.007 to 0.415 mm. in the centric relation position *(Celenza, 1971)*. This range has been considered clinically insignificant and the positions and pathways replicable. It is for this reason that prosthodontists have found it most convenient to use registrations on the border pathways.

The border pathways are not normally used by the patient at the occlusal level. The border paths have been termed articulator pathways and considered nonfunctional. Some claim these are pathways reached during bruxing movements. The border paths have been termed by Granger *(1962)* as power pathways and are potentially destructive should disharmony exist. These statements lack scientific evidence for their support. It appears that these border pathways are more prosthetically convenient and physiologically acceptable and are unrelated to the natural occlusal form.

Contained within the border pathways is an area in which the patient functions. The masticatory pathways lie within this area. There are no distinct borders defining this area, but a general pattern can be described *(Schweitzer, 1962)*. Balkwill *(1866)*, Bonwill *(1899)*, and Posselt *(1962)* have pointed out that a relationship exists between the occlusal morphology and the pattern, or outline, of the area of function. Schweitzer *(1962)* has shown that bolus resistance also affects the shape of this area. Posselt *(1962)*, Boucher, L. and Jacoby *(1961)* and Huffman *(1972)* have all shown that the pathways of motion can also be altered by anesthesia.



## TYPES OF MOTION

There are three types of motion that apply to the masticatory apparatus. They are rotation, translation, and plane motion.

Rotation is that type of motion where all points within the body scribe circular areas about a fixed line. The line is formed by fixed points and is called an axis of rotation. The points are called centers of rotation. Whenever rotation occurs, there must be an axis. All rigid bodies are permitted six degrees of freedom; three rotary and three translatory. This means that the body is capable of three-dimensional movement. The mandible is capable of rotation in three planes and must, therefore, have axes to describe the motion. Vertical rotation is controlled and described by the horizontal axis. The horizontal rotation is controlled and described by vertical axes, one for each condyle. The frontal rotation is controlled and described by sagittal axes, one in each condyle. These axes intersect at a common point center in each condyle. Since the planes are perpendicular to each other, so are the axes.

Translation is that type of motion where the points in the body glide or slide along paths that are parallel to each other. If the path is straight, the motion is called rectilinear translation. If the path is curved, the motion is called curvilinear translation. Most translation of the mandible is curvilinear.

All nonguided mandibular motion is a combination of rotation and translation. By analyzing the motion, plane by plane, we can convert the combination of rotation and translation into plane motion. Therefore, plane motion is a combination of rotation and translation in a given plane.

By resolving plane motion, we can determine the quantity of rotation and translation. In order to duplicate the motion, we must also know the timing of that motion. This can only be obtained from a dynamic registration.

## REQUIREMENTS OF AN ARTICULATOR AND REGISTRATION TYPES

Articulators (Class III and Class IV cast relators) are oriented to the temporomandibular joints and simulate certain permissible motions. The paths registered are those traversed by the condyles. The condylar pathways are a resultant of all of the elements in the masticatory system and not the joints alone. The articulator does not in any way resemble the anatomical form of the joints. All registrations made should be confirmed and, therefore, must be on paths that offer maximum replicability.

**THE CENTRIC REGISTRATION.** In order to obtain confirmation and permit vertical variation, a horizontal axis transfer is required. McCollum *(1955)*, Stuart *(1959)*, Granger *(1962)*, Lauritzen *(1964)* and Lucia *(1961)* reported a preference for a kinematic location of the horizontal axis. Bergström *(1950)*, Weinberg *(1963)*, Schuyler *(1959)*, and Guichet *(1969)* have shown that using average measurements for the axis transfer, produced small errors, and if the vertical variations are limited, the errors are insignificant. In restoring the occlusion of either the dentulous or edentulous patient, one should strive for maximum precision. In the edentulous patient, the attainment of the maximum precision may be impossible due to the multitude of clinical variables the prosthodontist must face.

**PROTRUSIVE REGISTRATIONS.** An articulator capable of accepting a positional protrusive registration, and all other eccentric records, must be of the arcon type as shown by Christensen *(1901, 1905)*, and Bergström *(1950)*. The instrument must permit angular adjustments of the condylar path. The path itself can be rectilinear or curvilinear. In order to accept a graphic registration of the protrusive path, the instrument must have an adjustable path capable of being customized in addition to the above requirements.

**LATERAL PROTRUSIVE REGISTRATIONS.** The lateral positional registrations provide the records to establish the rotational axes on the dental instrument. In order to accept the records, the instrument must have an adjustable intercenter distance to permit horizontal adjustment of the rotational centers. Varying the Bennett angle may appear to provide the needed adjustment for the instrument to accept the positional record. However, not all records can be accepted by merely adjusting the Bennett's angle. Acceptance of the records would be further facilitated by the addition of a superior-inferior tilt of the roof of the condylar path in the sagittal plane and a horizontal rotation of the path in order to position the angle of the rear portion of the path.

**ENGRAVING AND GRAPHIC REGISTRATIONS.** Engraving type registrations need to be positioned by an intercenter distance adjustment and then be copied by a path generation, or direct transfer of the record. Graphic registrations can be accepted if the instrument has an adjustable intercenter distance provision, complete Bennett adjustment, universal capability in the path position, and customization of the condylar path.



**DISCRIMINATORY CAPABILITY.** Discriminatory capability is that requirement of an articulator which permits the operator to alter the angular displacements *(Guichet, 1970)*. This capability is not possible with instruments designed to accept engraving registrations.

**PLANE OF REFERENCE TRANSFER.** In order to record eccentric settings for subsequent mounting procedures, the instrument must accept a reference plane transfer.

**SETTING SEQUENCE.** In order to accomplish the geometric setting and preserve the timing of the graphic registration, a certain sequence should be followed *(Beck, 1962)*. The horizontal displacements should be set before the sagittal displacements. The horizontal displacements are set in sequence; pure translatory displacement (immediate side shift), Bennett angle adjustment, rear wall angulation, and finally, the intercenter distance adjustment. The two sagittal displacements may be affected by the horizontal factors, while the reverse is generally not true. The anteroposterior path inclination (protrusive path) is set first. The tilt of the roof of the path is set last, establishing the Fisher Angle.

## THE EFFECT OF CONDYLAR PATHWAYS ON OCCLUSAL MORPHOLOGY

In closure, the mandible passes through many arcs, some of which are quite acute when measured from the horizontal plane. The most acute arc is the pure rotational closure dictated by the horizontal axis. Therefore, the horizontal axis may be considered a limiting factor on cuspal angulation. Straight vertical closure, perpendicular to the horizontal, or plane of occlusion, would permit a cusp angulation of 90°. Any lesser angulation would limit the cusp angle.

In the frontal plane, vertical masticatory strokes are perpendicular to the horizontal, or plane of occlusion, as compared with border pathways which have considerably less angulation. Therefore, one can consider pure rotational pathways and border pathways as limiting factors with regard to cusp angulation.

Aull *(1965)* reported the effects of changing the articulator end controlling factors on the occlusal morphology. The author assumed a cusp position and angle and then reported the effects on their relationship when the articulator angles were changed. In restoring the occlusion of the dentulous patient, the analysis of the articulation results in the proper positioning of the cusp to track the pathway. In the edentulous patient, the articulation usually requires modification of the occlusal surface of the supplied tooth to establish this harmony. The modification is accomplished by selective grinding or the waxing and casting of gold occlusal surfaces.

Angular displacements affect cusp height. The greater the angular displacement, the higher the cusp may be. The lesser the angular displacement, the shorter the cusp must be. With a given base, i.e., the horizontal plane or plane of occlusion, the higher the cusp, the steeper the angle. Angular displacements in the sagittal plane, such as the protrusive path inclination, affect the mesio-distal cusp angles. Angular displacements in the frontal plane, such as the orbiting path inclination which sets the Fisher Angle, affect the bucco-lingual cusp angle. In this situation, the effect is far greater on the orbiting side than on the working side.

An increase in the intercenter distance dictates a more distal placement of the lower grooves and cusp tips, and the reverse for the upper. A decrease in the intercenter distance dictates a more mesial placement of the lower grooves and cusp tips, and the reverse for the upper. Increasing and decreasing the Bennett angle affects the lower cusp tips and grooves in the opposite manner as increasing or decreasing the intercenter distance.

If there is a pure translatory motion in the horizontal plane, the effect would be to make the grooves in the same path as the motion. This would be the same for both upper and lower buccal and lingual grooves. The cusp tips would have to be moved distally in order to make way for the grooves. While this is true, it would be misleading to end the explanation of the motion here. It must be remembered that this motion (a pure translatory side shift) is a resolved motion and therefore only a portion of what is truly happening. Because the registration is made at a restricted vertical dimension, vertical rotary motion is not included in the record. We recombine the two motions when we restore the incisal guidance. Therefore, this type of motion does not dictate a flat occlusion, for the effect of the incisal guidance is the same as described in angular displacements in the sagittal and frontal planes.

## THE EFFECT OF ARCH FORM ON OCCLUSAL MORPHOLOGY

The positional relationship of the antagonist teeth have the greatest effect on cusp placement, regardless of the style of occlusion, be it cusp-to-fossa, cusp-to-marginal ridge, or a combination of both.

The overlap relation may be vertical or horizontal. Vertical overlap in the anterior region is related to the anterior guidance effect. Anterior guidance is, after all, the incisal guidance equivalent on the articulator. In the posterior region, an increase in vertical overlap will permit a steeper bucco-lingual cusp angle.



Horizontal overlap increase in the anterior region has the effect of nullifying the engagement of the incisal guidance. If the horizontal overlap distance is equal to the functional range contact, then the incisal guidance will be completely voided. This situation dictates posterior contact throughout the range of occlusal contact. An increase in horizontal overlap in the posterior region would have the effect of decreasing the steepness of the bucco-lingual cusp angle and increasing the bucco-lingual width of the occlusal table.

## ANATOMICAL CURVES AND PLANES

The curve extending anteroposteriorly (Curve of Spee and compensating curve), if increased in steepness, will require a decrease in the mesio-distal cusp angles of the posterior teeth. An increase in the steepness of the transverse curves (Curve of Wilson) will require a decrease in the bucco-lingual cusp angles of the posterior teeth. By tilting the plane of occlusion upward in the posterior, and downward in the anterior, the cusp angles will be decreased.

In general, for all adjustments and arch form manipulation, the effect on the occlusal morphology is as follows: if a change in adjustment in one direction decreases a cusp angle, then an opposite change will increase it. If the effect is to decrease the cusp angle, this is mandatory. If the effect produces an increase in the cusp angle, this is permissible but not mandatory, unless bilateral balanced occlusion is desired.

## SUMMARY

Our knowledge of articulators and articulation has greatly increased since the early 19th century, yet much remains for further study. The complexity of motion, the sophistication of instrument design, and the relationship between mechanical articulation and physiologic occlusion, particularly for the edentulous patient, will require additional research efforts.

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# Transfer of Maxillomandibular Relationships to the Articulator

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It is generally agreed that the contacts of the teeth in a complete denture prosthesis, in centric and eccentric positions, should be in harmony with the mandibular movement patterns of the denture wearer. This necessitates the recording of some maxillomandibular relationship(s) and its (their) transfer to an accommodating instrument. There is no universal acceptance of which maxillomandibular relationship(s) should be recorded, which method should be used in recording a given relationship, or which instrument to transfer it (them) to. This confusion is magnified clinically by the fact that recording bases are supported by tissues with varying degrees of resiliency. This imparts varying degrees of reliability to any of the recordings one may obtain.

The review of this subject is divided into three major categories: resiliency of the edentulous ridge, centric relation interocclusal records, and eccentric jaw relation records. Centric relation means many things to many people (*Avant, 1971*). Within the scope of this review it is defined as: "The jaw relation when the condyles are in the most posterior unstrained position in the glenoid fossae from which lateral movement can be made at any given degree of jaw separation." This is only one of five definitions offered in the Glossary of Prosthodontic Terms (*1968*). Although this position is generally accepted as a reproducible starting point for complete denture construction (*Kingery, 1952; Sharry, 1968; Hickey, 1964; Principles, Concepts and Practices in Prosthodontics, 1967*), methods of recording this position are varied. It is to this fact that the second division of this review is directed. Eccentric relation records shall merely be considered as a record of jaw relations other than centric relation. The adjective "interocclusal" was purposely left out so that pantographic records could be included.

## RESILIENCY OF THE EDENTULOUS RIDGE

Because the recording bases lie upon resilient ridges when recording jaw position and jaw movements, the operator, in all probability, is simultaneously recording base movements. Attempts to measure base displacements have varied greatly both in technique and amount measured. Årstad *(1959)*, in his review of the literature, reported the experiments of several early investigators. Holzman *(Årstad, 1959)* after attempting to set eccentric interocclusal records in an articulator, and having them vary as much as 60°, indicated displacement of the baseplates as the causative factor.

Kantorowicz and Schmitz *(Årstad, 1959)* placed one stud in each molar area and an adjustable stud on the anterior ridge area. The studs contacted the upper baseplate when occluding lightly. The adjustable stud could be raised or lowered as much as 2 mm., and when the patient bit down hard, he could bring all three studs into contact with the upper baseplate. A 1 kg. weight was then attached to the upper base, first in front, and then on the side. The plate lowered from 2 to 4 mm. without breaking its seal. When the upper base was then pressed against the ridge with the same weight, they lifted from 0.5 to 1 mm.

Pfeiffer *(Årstad, 1959)* made upper and lower vulcanite bases on six patients and cut them in half. The posterior halves were supplied with occlusion rims and the patient was instructed to close. The decreased vertical distance between the anterior halves was measured. This compression in the molar halves was found to be 1 to 3 mm. The procedure was reversed and the compression of the anterior region was found to be 0.5 to 4 mm. With finished prostheses, the patients were asked to bite hard and the change in vertical dimension was measured between points marked on the chin and nose. The maximum change in vertical dimension was 2 mm.

Under a 200 g. force, Sohm *(Årstad, 1959)* pressed an instrument with a 9 mm. diameter ball shaped tip into the mucosa of the maxillary ridge. It could be pressed 4.8 mm. into the anterior region. With variability, the displacement in other areas of the maxillary ridge was less.

Belger *(Årstad, 1959)* cut small segments out of upper baseplates made of vulcanite. Perforations were supplied with a cylinder and piston. With the baseplates under pressure, the pistons were raised 1.5 to 2 mm., which was read as displaceability of mucosa under dentures. Belger also found, by means of an extraoral pointer, that a single upper denture opposing natural teeth could be displaced 1.5 to 1.8 mm.

Boucher *(1940)* attached a tiltmeter to upper and lower acrylic resin baseplates and attempted to measure displacements with pressure on a central bearing point and a lateral bearing point. Measurements on the tiltmeter, with pressure on the central bearing point, indicated the bases were 0.06 mm. closer in the anterior, while the lateral pointer indicated no change. Measurements with pressure on the lateral bearing point indicated the bases were 0.08 mm. closer in both anterior and posterior regions. This apparatus was not capable of determining accurately the amount the edentulous ridges were moving under the baseplates.



Årstad *(1959)* studied the resiliency of edentulous ridges with several methods. Transparent acrylic resin baseplates were made for approximately 100 patients. A variety of impression procedures were used and some were scraped to provide relief for hard areas such as the torus palatinus. When pressure was applied to the crest of the ridge, extensive blanching of the mucous membrane resulted in a lifting of the baseplate at the point of the greatest distance from the pressure. Horizontal displacement was also observed and became more pronounced when the pressure was applied more obliquely. The displacement was not affected by the impression procedure used. The extent of displacement seemed to be dependent on the alveolar ridge and the nature of its soft tissues. Horizontal movements on the maxillary ridge were less when the maxillary tuberosities were firm and prominent, and were less on the mandibular ridge when the lower baseplate was extended posteriorly to cover a firm ascending part of the ramus of the mandible. Displacement was found to be 1 mm. in every direction on firm prominent ridges.

On three patients, Årstad *(1959)* made impressions with soft plaster. From the resulting casts, transparent acrylic resin baseplates with occlusion rims were constructed. When weight application to the positioned baseplates was increased from 2 to 4 kgs., the uneven contact and compression was marked. An increase of weight to 8 kgs. caused only slight change in the position of the baseplates. An increase in weight pressed baseplates further into the tissue, while the area in contact remained nearly the same.

Årstad *(1959)* also performed experiments on about sixty patients with finished complete dentures. Three straight wires in a face-bow arrangement were soldered and attached to the upper denture. It was determined that although there was great movement of the wires with empty gliding movements, masticatory movements on wax caused greater displacements. For two patients, plaster caps were made with wires attached to approximate the wires on the upper denture, the relative displacement in gliding and functional movements were similar to the previous experiments. The displacements of bases where the underlying ridge had well-developed tuberosities were smaller than on flat, flabby ridges.

On sixty-five patients with finished prostheses, Årstad *(1959)* remounted the dentures on a Hanau articulator and recorded interocclusal relations with wax, first in the mandibular second bicuspid and molars bilaterally, then in the mandibular cuspid-first bicuspid areas. These new relations were transferred to the articulator and the degree of displacements calculated. Experiments with prostheses on highly resilient ridges were thrown out. Calculations of displacements were; between the molars, a mean of 1.25 mm. with a standard deviation of ±.5 mm., while between the incisors, the mean was 2.59 mm. with a standard deviation of ±0.76 mm. The values are thought to indicate the displaceability of the soft tissues covered by the dentures in the molar and incisor areas, respectively.

Årstad *(1959)* also conducted an experiment on twenty-eight patients with complete maxillary and mandibular dentures, and two with complete maxillary dentures, to determine horizontal displacements caused by pushing in a horizontal direction. This was done with a graphic device. It was found that only lateral displacement of the maxillary denture could be measured accurately. Anteroposterior measurements of the maxillary denture and all measurements of the mandibular denture were impossible to measure with any degree of accuracy. The mean total horizontal displacement laterally was 2.13 mm. with a standard deviation of ±0.55 mm. All maxillary ridges were clinically prominent and firm.

Årstad claimed the resilient tissue was governed by Hook's Law of Elasticity and that during mastication, uneven compression of the mucosa is unavoidable. He concluded that "newly made dentures resting on firm and prominent residual alveolar ridges may be displaced in different horizontal directions about 1 mm. without loosening. They may, without loosening, be forced apart in the molar region about 1.25 mm., the incisors being in contact, and in the incisor region about 2.5 mm., the molars being in contact."

Lytle *(1962)* made casts from impressions of fifty-five edentulous ridges. The ridges showed evidence of soft tissue displacement caused by ill-fitting dentures. The dentures were removed for approximately sixty hours, allowing the tissue to recover. New impressions and casts were made. The casts, before and after recovery, were compared by the use of a dental comparator. His results show that soft tissue changes in the mandibular arch are greater than those in the maxillary arch. Lytle also showed the greatest displacement in the maxillary arch occurred on the crest of the ridge in the anterior region. The average displacement in areas of extreme abuse were found to be between 0.14 and 0.18 mm. Lytle also showed in several patients that changes under new dentures were much less than those found under the ill-fitting dentures. Other methods of investigation were also mentioned, such as cross section analysis of casts and cephalometrics.

Morris *(1966)* designed a study to measure denture base displacement and correlated it with forces exerted by the patient. Dentures with bite rims and lined with a tinfoil strip were constructed for one patient with a window leading to a simple manometer. Various waxes and impression plaster were the test materials for the checkbite procedure. Lateral oblique cephalometric roentgenograms were taken when the interocclusal bite registrations were being made. The cephalograms were analyzed for displacement of soft tissue by comparison to one lateral oblique cephalometric roentgenogram taken with no interocclusal recording medium and a pressure registration of zero. Impression plaster proved to be the least displacement-inducing material. The cephalometric measurement of tissueward movement of the mandibular denture base with impression plaster was in the order of 0.05 mm. in the retromolar pad and bicuspid areas. The force applied while making the interocclusal record was thought to be determined by the plasticity of the material, with impression plaster being the most plastic.



Kühl *(1970)* reported on studies regarding positions of the bearing point and its influence of tissue displacements. The position of the bearing point was altered both anteroposteriorly and laterally. Changes in dimension were measured between the bearing plate surfaces. The largest changes measured were made when the bearing point was in the midmost anterior position. In this position, the anterior measuring points separated an average of 0.6 mm., and the posterior reference points separated approximately 1.4 mm. Kühl states that the central position of the bearing plate device is a prerequisite for even pressure on the registration bases.

Interpretation and comparison of the findings presented must be made with great caution. Obviously, clinical experimentation in this area is very difficult. One must keep in mind that denture bases act as a single unit during gliding and function. Flexure of different denture base materials, as well as impression techniques, must also be considered. The movements of the bases are always measured in a relative fashion and procedural error cannot be disregarded. Variation of tissue resiliency between patients is as great as is the variability from one part of the same mouth to another. Årstad *(1959)* wrote, "Whether it is possible to make registrations without incorporating independent movements of the baseplates or the dentures to which the registration medium have to be attached, is impossible to prove."

## CENTRIC RELATION INTEROCCLUSAL RECORDS

The dental literature is repleat with "techniques" for recording centric relation. Kingery *(1952)* recognized the "confusion caused by the number of methods advocated and the arguments advanced in support of each method." For discussion purposes, he classified the techniques as: **a.** *Graphic* methods employing a graph or tracing as guides for a checkbite, i.e., extra oral or intra oral procedures. **b.** *Direct checkbite recording,* or **c.** *Functional recording,* i.e., chew-in procedures.

The review of this section will be limited to comparisons of the various techniques.

Trapozzano *(1949)* was concerned about equalization of pressure while recording centric relation, and compared an intraoral technique with an interocclusal wax record. He reported that in complete denture patients with good ridge support, it is possible to obtain equalization of pressure by means of the central bearing point. Also, that by means of wax interocclusal centric relation records, duplicate centric relation records could be made which check accurately with each other, not only anteroposteriorly, but for equalization of pressure. In a second series of experiments, a group of patients with "off-ridge" conditions (Class II, Class III and crossbite) and unyielding tissues, the two techniques again checked accurately. In another group of patients with off-ridge relations and normal-to-easily displaced tissue, the two techniques checked accurately in an anteroposterior direction but not for equalization of pressure. In this group, he found the wax interocclusal records checked repeatedly with each other, but the intraoral tracing technique would not check for equalization of pressure, even after the central bearing point was repositioned several times. "This," Trapozzano cautioned, "was the effect of the patient having to keep the bearing point in contact with the bearing surface." He felt that considerable experience is necessary for making adequate wax checkbite records. Sample size and measurement data were not reported.

Kapur and Yurkstas *(1957)* conducted a study to evaluate commonly used methods of recording centric relation. The three methods studied were: **a.** Stansbery's extraoral tracing procedure, **b.** Hardy's intraoral tracing procedure and **c.** Hanau's wax registration procedure. With the wax interocclusal registration procedure, the tongue tip was placed behind the posterior palatal edge of the maxillary baseplate to position the mandible in its retruded position. Three interocclusal centric relation registrations were recorded with each method on each of thirty-one complete denture patients. The evaluation was performed on an instrument similar to the Hooper duplicator. It was modified to facilitate the recording of changes produced by the various techniques. A statistical analysis of the results was performed which showed the intraoral and extraoral tracing procedures were more consistent as compared to the wax registration technique. In patients with flabby ridges, the tracing procedures became less consistent as compared to their consistencies in patients with good, and with flat ridges. The authors wrote that, "The consistency of the extraoral tracing procedure did not vary significantly in patients with different types of ridges. The degree of consistency of the intraoral tracing procedure decreased to a significant level in patients with flabby ridges." The wax method showed the least consistency on flat ridges and the highest consistency in the flabby ridge groups. The differences in consistency between the intraoral tracing procedure and the extraoral tracing procedure were not statistically significant. They found the mean deviation in millimeters of all three methods approached 0.2 to 0.4 mm., and that this amount, in the case of an edentulous patient, is barely perceptible clinically.

Årstad *(1959)* attempted several methods of functional registrations and found the techniques unsatisfactory. Base movements, biting pressures,



and resistance of recording materials were the main deterrents.

Nevakari *(1961)* compared four methods of recording centric relation; two graphic and two static. The two graphic methods were those of Gysi and Stansbery. The two static methods were the common interocclusal wax bite and the maximally retruded interocclusal wax bite. The maximally retruded interocclusal wax bite was differentiated by having the patient bend his head backwards and placing the tip of his tongue at the posterior border of the maxillary baseplate in an attempt to place the mandible in its most retruded position. The clinical subjects included twenty males and twenty females. An attempt was made to choose twenty favorable ridge conditions and twenty unfavorable ridge conditions. The same acrylic resin baseplates were used, but the occlusal rims were different. Measurements were made from Posselt's Gnathothesiometer. Two successive registrations were made with each technique and the estimated error was calculated to be 1 mm. in any direction. The results showed that no method gave the same measurements at all three recording points in two successive determinations. When the vertical dimension at the anterior measuring point was disregarded, the same results in all measurements on two successive occasions was obtained in seventy-three instances. Of these, twenty-eight were obtained using the wax bite method, eleven with Gysi's method, seventeen with Stansbery's method and seventeen with the maximally retruded method. In 85% of the favorable cases, the maximally retruded wax bite method gave a 0.5 to 2.0 mm. more distal result than the other methods. Regardless of the method used, the differences were larger in the lateral direction than in the sagittal plane and the maximal retruded wax bite method yielded the largest differences. In the condylar areas, the differences in the successive determinations were in the 0.5 to 1.5 mm. range, indicating the recording plates had been rocking.

Nevakari concluded that: **a.** the degree of uncertainty in determining centric relation in favorable cases is approximately the same for all methods studied, **b.** in unfavorable conditions, the intraoral techniques are more useful, **c.** the maximally retruded bite generally yielded a registration of .5 to 2.0 mm. to the distal, (however, this method may have registered a sliding baseplate rather than a jaw position), **d.** there is no systematic difference between previous denture wearers and beginners, or between sexes, e. there is no reason to use the more complicated graphic techniques because the results are no better, and f. the degree of uncertainty with all methods makes it desirable to selectively grind the complete denture occlusion so that balanced occlusion prevails 1 mm. in any direction around the centric relation recorded.

Walker *(1962)* compared a graphic extraoral tracing method to a swallowing method for recording centric relation. He used both techniques on twenty-one edentulous subjects with residual alveolar ridges as nearly ideal as possible. Walker's analysis was performed on an instrument that he designed for his experiment. The instrument was similar to Posselt's Gnathothesiometer. A statistical analysis of the data indicated that there was significant difference in the results obtained by the two methods. The pattern of registrations for swallowing appear forward and below that of the graphic method. Therefore, Walker concludes the act of swallowing was shown to be unreliable for the registration of centric relation.

Michman and Langer *(1963)* compared three methods of recording centric relation in edentulous patients. In the first group of 137 patients, centric relation was recorded with the wax interocclusal record. Swallowing was used to position the mandible in its retruded position. The correctness of this procedure was judged by one of the authors after the dentures were completed. Seventy-one percent were judged correct and 29 percent incorrect. Dentures for the second group of 179 patients were constructed using an intraoral graphic tracing device. The accuracy was judged, as in the previous group, by examination of the finished dentures in the mouth. Eighty-six percent were judged correct and 14 percent incorrect. In the third group of 123 patients, the wax centric relation record was taken with all the maxillary teeth set against posterior bite rims and the six anterior teeth set on the lower baseplate. As in the first group, swallowing was used to determine the centric relation position. This method was checked against a centric relation record taken with the Coble Balancer. Ninety-six percent were judged correct and 4 percent incorrect. No measusrements were reported. All determinations were subjective observations made by the authors.

Yurkstas and Kapur *(1964)* did not directly compare techniques, but clinically evaluated factors which influence the wax interocclusal record technique and the graphic intraoral technique. The sample included thirty-five edentulous patients and comparisons were made by analysis on a tripod-like instrument similar to the Hooper duplicator. The authors wrote, "In the wax recording procedure, the consistency of the recording wax, its degree of hardness, its degree of bilateral homogeneity, the amount of occlusal contact, and the presence of anterior freedom, influenced duplicability to a significant level." They suggested that there should be no closing pressures or contacts in the anterior. The wax should be soft, placed only in the bicuspid and molar areas, and be bilaterally homogeneous.

For the intraoral tracing procedure, the authors concluded that, "The location of the central bearing point, anteriorly, posteriorly or laterally, the inclination of the central bearing point in relation to the tracing plate (whether it be perpendicular or mounted at an angle to it), and the inclination of the tracing plate in relation to the underlying bearing surfaces played an important part in determining the duplicability of the records." To achieve greatest clinical accuracy, minimal closing pressure must be exerted during its execution and occlusal focus must be centralized and equally distributed to the underlying ridges.



Kühl and Frank *(1966)* constructed twenty-five complete maxillary and mandibular dentures. Some were constructed using an intraoral graphic recording and the remaining made using wax interocclusal records. After wearing the dentures for three weeks, and remounting with an intraoral recorder (which was presumed correct), it was shown that the wax interocclusal record dentures had occlusal disharmonies and were generally more troublesome.

Glantz *(1966)*, with ten edentulous patients, compared the Hanau simple wax interocclusal technique with the Stansbery extraoral graphic technique. Measurements for analysis were made on a crank slide rest with accuracy to one-hundredth of a millimeter. The results showed that the variation was smaller in width as well as more retruded for the Hanau technique. These findings are statistically significant. However, there are variations as great as 3 mm. between the results of both methods, and in no case were two identical results achieved.

Kühl *(1967)* reported observations in ten treated edentulous patients. He found that occlusal discrepancies, when using wax interocclusal records, may cause distractions in the temporomandibular joint. Lateral nonocclusions in the premolar and molar areas, not clinically seen in the mouth, showed in distractions of the temporomandibular joints.

Kühl and Rossbach *(1968)* compared swallowing interocclusal checkbites with Gothic arch checkbites in forty-five patients. When the two procedures showed a great variation, two dentures were constructed; one in the position determined by swallowing and the other occluded in a position approximately 1 mm. posterior to the apex of the Gothic arch. The patients preferred the second denture.

Grasso and Sharry *(1968)* reported a study on the duplicability of the arrow-point (Gothic arch) tracing in dentulous subjects. The objective of the study was to determine whether the apex of arrow-point was constant over a period of time in subjects with a sound dentition. Fifteen male subjects were chosen. Acrylic resin appliances were made to cover the dentitions. Bearing points were added to the upper appliances and receptacles to accept milled steel plates (bearing surface) were created. Each subject recorded three consecutive Gothic arch tracings on the first, fifth, fifteenth and twenty-ninth days. The milled steel plates, with the graphic tracings, were measured in a micrometer-like instrument. Two readings were made of each tracing in both the anteroposterior and lateral directions. The results showed the average variation in the anteroposterior direction as 0.25 mm. and in the lateral direction 0.44 mm. Nine of the fifteen subjects had a variation pattern that was more wide than long. The variability of the apex position occurred over one day, and twenty-nine day periods. Grasso and Sharry suggested that perhaps the primary control of border movements is muscular and not ligamentous. They also stated that no conclusions were possible concerning the size of the area of variability in denture patients, because the resiliency of the basal seat was a variable not encountered in the experiment.

Preti *(1969)* constructed eight complete dentures with wax interocclusal records and eight dentures using an intraoral graphic device, (according to the technique of Gerber). The dentures were analyzed and the results pointed to the advantages of the central bearing point technique.

Marxkors *(1970)* compared Jankelson's stretch-reflex method to an intraoral technique (McGrane). It was found that in about 50 percent of the cases, the mandible is retruded further with the stretch-reflex technique.

Helkimo, Ingervall, and Carlsson *(1971)* reported a study of variations in recording the retruded position and muscular position of the mandible in ten dentulous subjects. Acrylic resin splints were fabricated for each arch. The maxillary splint held interchangeable waxed glass slides and the mandibular splint carried a central bearing point. They found the retruded position (operator guided) was the more repeatable position, whether achieved by terminal hinge movement, or by tracing the Gothic arch. It was not affected by the subject's posture (lying or sitting), or the position of the operator (right or left). The accuracy was nearly the same in the anteroposterior and medio-lateral directions. The muscular position exhibited less precision and was found to be the furthest anterior while standing, and the further posterior while lying. They concluded that because of its reproducibility, the most retruded position is suitable as a reference position in functional analyses of occlusion.

The difficulty in analyzing clinical research comparing various centric relation registration techniques stems from the lack of a standard reference position. It is impossible to determine which technique records the correct centric relation jaw position.

## ECCENTRIC JAW RELATION RECORDS

Eccentric jaw relation records are generally used to set the condylar and lateral condylar guidances of semi-adjustable and adjustable articulators. This articulator guidance is thought to approximate the condylar guidance in the patient. However, "the role played by the temporomandibular joints as guidance is still a controversial subject" *(Posselt, 1960)*. Some authors *(McCollum and Stuart, 1955)* claim that condylar guidance is a definite determinant of mandibular movements. Posselt found this in contradiction to the findings of Wustrow *(1918)*. Wustrow placed a glass ball between the teeth on one side of a patient's dental arch and when the patient closed with force, it appeared the working condyle moved vertically away from the fossa while the balancing condyle appeared to move further into the fossa.



Posselt *(1960)* performed an experiment with the McCollum Gnathograph fixed to a patient with natural dentition. Changing the tooth guidances and allowing the patient to chew did not change the registrations of the sagittal condylar paths. Other authors have found similar results *(Cohen, 1956; Clayton, Kotowicz and Myers, 1971)*. Munzesheimer *(Posselt 1960; Årstad 1959)* found similar results in complete denture patients. Posselt repeated Wustrow's experiment with a steel ball and found similar results. However, biting on a hard gutta percha ball (which allowed tooth indentation) did not show a stylus deviation from the sagittal path registration as occurred when biting on the steel ball. Posselt noted that gliding movements in all possible directions did not produce a linear condylar path in the sagittal plane. This, he asserted, is not an error in the tracing, but merely a two-dimensional projection of a three-dimensional movement surface. Posselt's findings confirm the results of McCollum *(1939)* and Stuart *(1959)* in that identical paths of the condylar styli are recorded regardless of tooth guidance. He found that definite paths were recorded during empty glidings and during chewing movements. Posselt *(1960)* wrote, "Sicher made the point that when noncontact movements are carried out within limits of the movement space, the character and shape of the temporomandibular joints are of no significance for the movements of the mandible. However, when contact movements are performed, the path of a molar cusp, for example, is influenced by both incisal and condylar guidance." Posselt stated that contact and border movements are important for two reasons:

1. "Teeth and joints influence mandibular movements when the upper and lower teeth make contact. Such contact movements are relevant in obtaining stress distribution in restorative and prosthetic work.
2. Reference movements and positions as used in bite registration are generally of the extreme border type."

Records of eccentric occlusal positions in the horizontal plane are made in protruded and lateral positions. These static positions can be made with both intraoral (static and functional) and extraoral techniques. "The three most common techniques are with checkbites with wax, positional records of stone or plaster and, lastly, by means of pantography," *(Sharry, 1968)*. This review will be directed toward the reproducibility of a given technique and comparisons of combinations of the mentioned techniques.

Gysi wrote, "Checkbites with wax or compound are necessarily so unreliable as frequently to lead prosthetists into grave errors." He also wrote, "We have never been able to get the same registration twice on the same patient at the same sitting and I have never found anyone who could. The results differ from 5° to 25° above or below the individual conditions."

Craddock *(1949)* recorded multiple protrusive and lateral wax interocclusal records and made roentgenograms (after Lindblom) on three dentulous patients. He analyzed the articulator settings and roentgenograms and found the use of intraoral wax records of eccentric jaw relations for the adjustment of horizontal condylar guidance on anatomic articulators to be invalid and unreliable. He mentioned that "to get an eccentric interocclusal record that can be used, the degree of protrusion is beyond the functional range." Craddock believed the inconsistency would be greater in complete dentures because of tissue resiliency and that a change in 10° horizontal condylar inclination produces a change of 0.5 mm. in the second molar region.

Narbe and Årstad *(1950)* experimented with Stansbery's and Gysi's techniques. They stated, "Provided the centric position is correct, exact adjustment of the condyle path of the articulator is not of vital importance, because the resilience of the mucosa will to a certain extent compensate any such incorrectness."

Årstad *(1959)* made cross comparisons of articulator settings for various techniques of recording eccentric movements for seven complete denture patients. The techniques included those of Gysi (with central bearing point), Stansbery, Hanau, and the engraving and chewing-in methods. He found that only Gysi's and Stansbery's technique yielded any consistency in recorded articulator values. This was not found for all patients. He concluded that none of the methods using situational interocclusal records can be considered reliable when a thermoplastic material is used, and that functional engraving or "grinding-in" techniques register movements of the mandible plus those of the bases on the soft tissue. Årstad believed that none of the methods mentioned guaranteed a correct registration of mandibular movements. He advocated the use of an average value articulator rather than being uncertain about the time-consuming task of recording mandibular movements in the edentulous patient.

Posselt and Franzén *(1960)* performed a study similar to that of Craddock. Multiple protrusive wax interocclusal records were taken on three dentulous patients. The results showed a slightly less, but still considerable, standard deviation. The errors were not so large that the actual values of the recordings were thought meaningless. The large variation, among other things, was thought due to the error of a tipped cast being magnified in the condylar area. In a second part of the same study, using ten patients, Posselt showed that the amount of protrusion recorded should be 4 mm. He thought that 6 to 8 mm. was best from a mechanical standpoint and 2 mm. most favorable from a physiological standpoint. Four mm. was suggested as a compromise. The data was collected from three instruments; the Dentatus articulator, the Bergström articulator and the Gnathothesiometer. The two articulators compared favorably, but the unreliability of the Gnathothesiometer was greater than the Bergström or Dentatus instruments.



Posselt and Skytting *(1960)* also reported a study of ten dentulous patients in which multiple protrusive recordings were made with the Gysi technique (modified slightly by using lateral excursions). He found the error of the graphic method to be about twice that of the intraoral wax method (±5.4° as compared to ±2.3°). He felt the error was mainly caused by difficulty in drawing a tangent to the curved condylar path rather than the recording, and that the problem is overcome in the pantographic technique.

Posselt *(1961)* investigated the frequency of condyle path inclination as determined by the protrusive wax interocclusal record. One hundred and one dentulous subjects were used. As related to the Frankfort plane, the greatest frequency was found to be between 40° to 50°. He found that the condyle path registration by means of wax interocclusal records possesses some value. Ekensten *(Posselt 1961)* found that wax interocclusal records (from edentulous patients) were favored over the Gysi's graphic registration.

Dubois *(1966)* conducted a study to determine if changes occur in the protrusive condylar inclinations during the first ninety days that complete dentures were worn. Ten edentulous patients with firm, healthy mucosa were selected as subjects. Recordings were made during construction, at delivery and ninety days after insertion. It was found that five condylar path inclinations decreased and fifteen increased after ninety days. In most instances, it was found that if the condylar guidance inclination used in the denture construction was steeper than the condylar path inclination at the time the dentures were inserted, the condylar path inclination became less steep after wearing the denture ninety days. If it were less steep, as recorded during construction, it became steeper. He concluded that the condylar path may change during the first ninety days following denture construction. Dubois advocated the use of correct condylar inclinations in complete denture construction.

Langer and Michman *(1970)* evaluated the lateral tracings recorded intraorally with a Coble Balancer on 139 edentulous subjects. They retraced the lateral movements on the Hanau model H articulator and set the lateral condylar inclinations. The lateral condylar inclinations were then calculated using Hanau's formula and the settings of the two methods compared. They found that the tracings of 114 subjects (82 percent) were within a range of 17 ± 2° of the lateral condylar adjustment on the articulator.

Frazier, *et al.* *(1971)* examined the relative repeatability of plaster interocclusal records for articulator adjustment in the construction of complete dentures. A kinematic face-bow transfer was made to a Whip-Mix articulator. A centric relation plaster interocclusal recording was used to mount the mandibular cast. The selected artificial teeth were set and the centric relation mounting verified. With the teeth set in wax, multiple protrusive, and right and left lateral plaster interocclusal records were recorded by three different dentists. Each dentist used the records he made to adjust the articulator. Articulator calibrations were read and recorded by a trained dental assistant. In an additional part of the study, four dentists set the instrument to plaster interocclusal records taken from casts mounted in an articulator with known condylar settings. After a statistical analysis, they concluded that the greatest error occurs in making the record. Each dentist was highly consistent with himself for a given patient but was not as consistent with other dentists using the same patient. Plaster interocclusal records in the protrusive and lateral positions were thought repeatable enough to render them useful as a basis for treatment.

The principles involved in the pantographic technique, their practicality, and their reproducibility, have been questioned by many authors *(Hall, 1929; Kurth, 1942, 1954; Sheppard, 1958; Landa, 1958; Shanahan and Leff, 1959–1964; Page, 1964; Watt, 1968)* and advocated by others *(McCollum, 1939; Cohen, 1956; Posselt, 1960; Kotowicz, Clayton and Smith, 1970; Clayton, Kotowicz and Myers, 1971; Clayton, Kotowicz and Zahler, 1971)*. Pantography has been noted for its advantages in the recording of jaw movements, but has not been totally accepted by complete denture prosthodontists because of the heavy equipment and movable bases encountered with this method *(Sharry, 1968)*. Kotowicz, Clayton and Smith *(1970)* found pantographic-recording reproducibility to be a practical quality of border movements in dentulous patients. Lucia *(1961)* and Guichet *(1969)* illustrated the use of the pantograph in complete denture prosthesis. Research concerning duplicability of tracings or articulator settings for edentulous patients could not be found.

While the materials used in complete denture construction have been steadily improving, the procedures of recording and transferring jaw relations have not. There has been no noticeable change since the early part of this century. Efforts by dentists to improve complete denture construction (i.e., recording eccentric jaw relations and using adjustable articulators) are often considered too time-consuming for any advantages gained, when considering the movement of the denture bases. Correspondingly, clinical research on the treatment of edentulous patients is deficient.

If a balanced and stable occlusion is desirable, it is necessary to program more information into the articulator than just a centric relation jaw record. This, in fact, is more true than if an occlusion with no balancing contact is desired. Sophisticated techniques must first be proven as to their degree of effectiveness before they can expect to be accepted by the majority of practicing prosthodontists.



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# Occlusion as Related to Complete Removable Prosthodontics

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Occlusion of complete dentures has been a concern since ancient times when attempts were made to replace lost teeth. Teeth carved from ivory and fastened to gold plate have been found in mummies dating back more than 2,400 years. Others found were made of bone and wood. Although those who practiced this art of carving possessed certain degrees of skill the occlusal surfaces may be said to be nondescript or unclassifiable and often of several forms in the same series of carvings.

Among the principal contributors in the development of posterior denture teeth of different occlusal forms in the last 50 years have been Sears *[1953]*, Gysi *[1929]*, Hall *[1929]*, French *[1954]*, Kurth *[1954]*, and Hardy *[1951]*. Many other occlusal forms appear to be modifications of the original patterns.

The designs of posterior teeth generally have been based on the morphology of the natural teeth and the temporomandibular joints, observation of movements of the mandible, clinical observations of wear facets on the natural teeth, chewing efficiency, and/or empirical and subjective values assigned by the designers based on clinical experience and judgment. Other contributions have been made in other continents. Thus, a variety of occlusal forms have been accepted for complete dentures without long-term investigations and statistical analyses of the advantages which may be attributed to each form.

Woelfel* recently reported on a five-year clinical study of a comparison of three occlusal forms, i.e., 0, 20, and 33 degree teeth in complete dentures. He suggests as one result of his study that the selection of 0 and 20 degree teeth should be based on other factors than an attempt to maintain the supporting structures of the dentures. Another long-term study of a different nature relates tooth form to two different techniques. It was begun several years ago and hopefully will disclose further statistical

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*Woelfel, J. B.: Personal communication.

significance after the ten-year period of study is completed. Progress of the study has been reported by Hickey, Henderson, and Straus *[1969]*.

Payne *[1955]* listed definable guidelines for the selection of occlusal patterns based on anatomic oral tissue conditions and jaw positions in centric relation. A chart which outlines the selections has been exceedingly helpful for dentists who do not strictly subscribe to one tooth form and concept for all patients.

In the broadest sense, complete dentures should fulfill the requirements of (1) esthetics, (2) harmonious function, and (3) maintenance of hard and soft tissues of the edentulous arches. Important contributions enabling the dentist to attain these goals have been made by the Academy of Denture Prosthetics through periodic publications *[Schuyler, Jordan and Sears, 1952 and 1953; Academy of Denture Prosthetics, 1963; and Lytle, Atwood and Beck, 1968]*. Important information and suggestions have been detailed in statements covering various phases of prosthodontic treatment including conditioning and preparation of the patient for dentures, the making of impressions, the recording of jaw positions, the transfers of records, and the use of articulators, as well as provisions for an esthetic denture. Very little guidance is given for the selection and arrangement of one or more occlusal forms of denture teeth, except in stating that bilateral balance is desirable and that teeth should allow for unlocking in centric occlusion.

## ESTHETICS

One of the factors in developing an esthetic denture is dependent upon the reaction of the patient and the dentist to the color (shade) of the teeth to be chosen. Color is a three-dimensional entity consisting of hue, chroma, and value.* Hue is the designated color such as red, yellow, or green. Chroma is the strength or purity of the color, and value is the lightness or darkness of the color as compared to a gray scale ranging from white to black.**

Another factor to be considered in esthetics is the arrangement of anterior and posterior teeth. Judicious proximal spacing between the teeth will result in depth perception. Tinting of the bases where they are visible will add to depth perception by the observer.

## HARMONIOUS FUNCTION

Harmonious function of complete dentures is the requirement which exhibits harmonious occlusal contacts in centric and eccentric maxillomandibular relations and which is in harmony with the neuromuscular mechanism and the temporomandibular joints in the functional ranges of speaking, chewing, and swallowing, and with parafunctional movements including "exploratory or nonfunctional movements."*** In narrowing the part of function applicable to the occlusal and incisal areas of the denture teeth, occlusal balance is defined as, ". . . a condition in which there are simultaneous contacts of the occluding units on both sides of the opposing dental arches" *[Boucher, C. O., 1963]*. This definition can be applied to centric occlusion as well as eccentric occlusal contacts.

*Munsell Color Order System, Munsell Color Company, Inc., Baltimore, Md.
**Sproul, R. C.: Personal communication.



Occluding units in complete dentures under functional contacts away from centric occlusion are referred to as being in a balanced occlusion or in a nonbalanced occlusion.

A balanced occlusion is defined as ". . . the simultaneous contacting of the upper and lower teeth on the right and left sides and in the anterior and posterior occlusal areas of the jaws. This occlusion is developed to prevent a tipping or rotating of the denture base in relation to the supporting structures" *[Boucher, C. O., 1963]*. It must follow that a nonbalanced occlusion would not fulfill the conditions of simultaneous contacting of the upper and lower teeth in eccentric positions. The question of immediate concern is how far from centric occlusion do teeth contact in their functional ranges and how far should potential deflective contacts be avoided to eliminate tilting or rotating actions on the denture bases?

Jankelson, Hoffman, and Hendron *[1953]* suggested that there were not enough factual reports in the literature to substantiate a balanced occlusion. They further suggested, as evidenced by cinefluorographic studies, that centric occlusion is the only tooth contact of any significance. They stated that, "There was no evidence that balance of teeth in eccentric positions is a physiologic necessity, or that lack of eccentric balance is less conducive to masticatory function." The cusp angulation in six patients who had 0 to 45 degree cusp teeth in dentures appeared to have no influence on the manner of incision. Occlusal balance was not observed as long as the bases remained in contact with the supporting tissues. The influence of the tongue in retaining the dentures, however, was obvious.

Yurkstas and Emerson *[1954]* reported that twelve patients with nonanatomic teeth (0 degree) in dentures had considerable contact of teeth on the working sides, and nearly 100 per cent had contact on the balancing sides. Dentures made with post-molar ramps exhibited no contact on the working sides but did show some contact on the balancing sides. Their investigation was comparable in method to part of that of Jankelson, Hoffman, and Hendron *[1953]*.

***Larkin, J. D.: Personal communication.

Brewer and Hudson *[1961]* used radio signals to record chewing contacts of teeth. This procedure was the first to eliminate direct wiring out of the mouth to the recording unit. This pilot study on two patients showed that chewing contacts occur on the cusp heights as well as in centric occlusion. A later report by Brewer *[1963]* indicated that the type of cusp form and harmony of balanced occlusion caused variation in the number and type of contacts.

Experiments with natural teeth by other investigators disclosed contacts in the intercuspal position, increasing in frequency toward the end of mastication. *[Anderson and Picton, 1957]*. Lateral tooth contacts did occur although less frequently than in the intercuspal position, and they occurred before and after the centric occlusal contacts were reached. *[Adams and Zander, 1964]*.

## MAINTENANCE OF HARD AND SOFT TISSUES

The maintenance of hard and soft tissues of the dental arches is difficult to relate to occlusal patterns and occluding concerns alone. Other factors, such as (1) properly fitted bases, (2) correct jaw relation records and transfers to an instrument capable of holding what is recorded, and (3) the arrangement of teeth for the best stability, and other procedures have an influence on tissue maintenance. Undoubtedly, occlusal patterns and the types of occlusions developed must exert considerable influence on the soft and hard tissues. When more long-term independent studies with statistical evidences are completed, guidelines for the selection of occlusal patterns may be forthcoming. Investigations as designed by Woelfel* and by Hickey and associates *[1969]* have stimulated further research in depth and scope. The Academy of Denture Prosthetics should then be in the position to include definable guidelines for occlusal concerns in its publications *[1963]*.

Ten contemporary occlusal concerns will be reviewed by schematic drawings, several of which appear to be used more than others. Of these, the first five are in the balanced occlusion concept, and the remaining five are in the nonbalanced category in eccentric occlusal positions. Undoubtedly, more exist, but they should be in one of the ten categories by virtue of being modifications. Detailed techniques and procedures, efficiency and mastication performances will not be evaluated. However, forces exerted by tooth contacts which could be transmitted to the basal seat areas are illustrated in the diagrams. The directions of these forces are usually perpendicular to the opposing surfaces in gliding contacts. Small frictional forces present would alter the directions by small unknown amounts, and variations in the positioning of the teeth to obtain a balanced occlusion would also alter the directions of these contact forces.

*Woelfel, J. B.: Personal communication.



## BALANCED OCCLUSIONS

(1) The definite cusp form which represents anatomic and semi-anatomic configurations dates back to 1909 when "twentieth-century anatomical bicuspids and molars" were introduced by the Dentists' Supply Company.** This culminated in the 33 degree cusp form in 1914 as advocated by Gysi *[1929]* (Fig. 1, A). A classical lateral movement is shown where cusps contact bilaterally to enhance the stability of the dentures (Fig. 1, B). Fig. 1, C and D, depicts deflective contacts in extreme lateral positions which may cause tilting actions of the bases.

**Dentsply International, York, Pa.

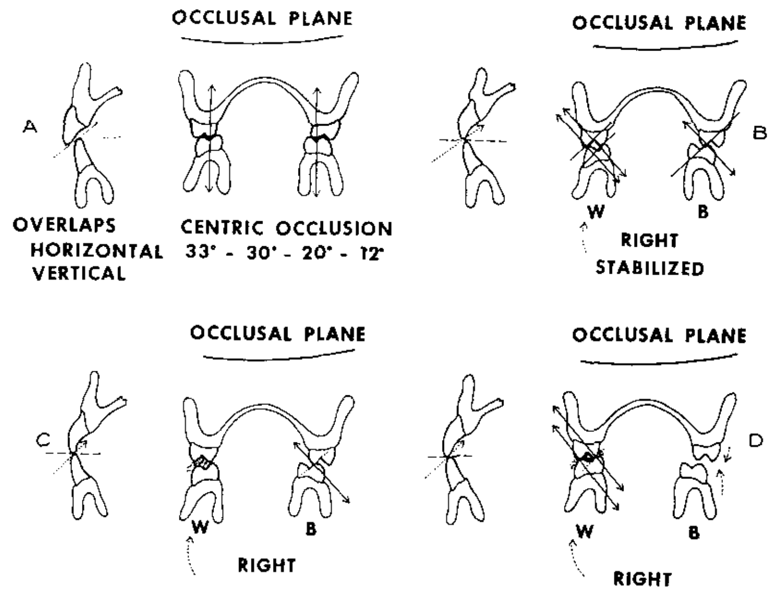


Fig. 1. *(A)* Diagram of anatomic or semianatomic cusp teeth in centric occlusion with overlaps in the anterior region. The composites of the contact forces are directed toward the ridges. *(B)* From a right lateral movement, cusps glide on opposing inclines. Although bilateral contacts stabilize the dentures, the contact forces are directed away from the ridges. *(C)* In a condition of deflective occlusal contact on the balancing side, the contact force is directed outside the ridges. *(D)* In strong working-side contacts on both cusp inclines, contact forces are also directed outside of the ridges.

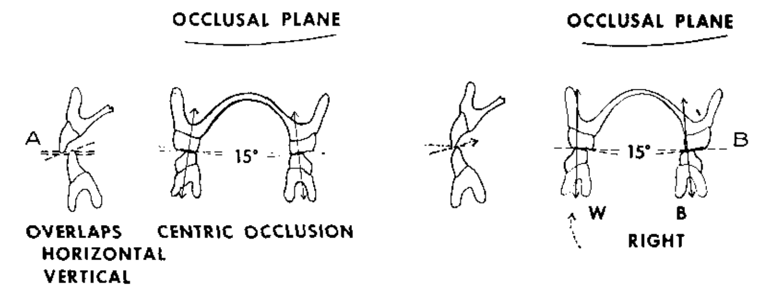


Fig. 2. *(A)* In centric occlusion, half of the width of lower posterior teeth helps to direct the occlusal contact forces on the lingual side of the ridges in a buccal direction to the lower ridge. *(B)* From a right lateral position toward centric occlusion, the contact forces are directed toward the ridges on the working side *(W)* and away from the ridges on the balancing side *(B)* (French's posterior teeth).

(2) Fig. 2, A and B, illustrates the reduction of the occlusal table of the lower posterior teeth to increase the stability of the dentures as advocated by French *[1954]*. The upper posterior teeth have slight lingual occlusal inclines of 5 degrees for the first bicuspids, 10 degrees for the second bicuspids, and 15 degrees for the first and second molars, so that a balanced occlusion could be developed laterally as well as anteroposteriorly by the arrangement of the teeth on a curved occlusal plane.

(3) Sears *[1953]* was one of the greatest exponents of the nonanatomic tooth forms. He introduced his chewing members in 1922 and his channel type posterior teeth in 1927. These teeth had a restricted acceptance at first. Modified nonanatomic tooth patterns from the early types have been accepted much more extensively since then. A balanced occlusion can be developed by a curved occlusal plane anteroposteriorly and laterally or with the use of the second molar ramp (Fig. 3, A and B).

(4) The next occlusal concern employs a posterior reverse lateral curvature except for the second molar which is set with the customary lateral curvature (Wilson curve) to provide a balanced occlusion (Fig. 4, A and B). Pleasure *[1953]* rationalized that the occlusion should be of special design due to the instability of the lower denture. Resultant forces should be directed vertically and/or lingually. He further envisioned that research should result in a machine which could test, ". . . (1) the forces encountered in closing through food; (2) the number of chewing cycles required; (3) the amount of lateral displacement induced in the tooth support during a normal chewing cycle against resistant food." He stressed that forces of cutting and shear with a reduction in the displacement of bases are more important than the triturating efficiency to evaluate posterior tooth form in terms of maintaining the supporting structures.



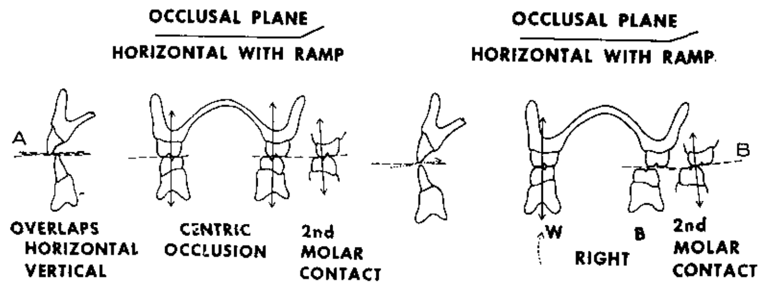


Fig. 3. *(A)* Nonanatomic teeth will exert contact forces toward the ridges in centric occlusion. *(B)* From a right lateral position toward centric occlusion, gliding surfaces will direct contact forces toward the ridge on the working side *(W)* but will direct contact forces toward the buccal side of the ridges on the balancing side *(B)*, depending on the degree of lateral inclination of the second molars.

(5) The last occlusal design in the balanced category employs an arbitrary articulator balance, followed by intraoral corrections to obtain balance, and it illustrates a linear occlusion which is intended to give a one-dimensional contact between the opposing posterior teeth as advocated by Frush *[1967]* (Fig. 5, A and B). A blade on the lower posterior teeth contacts essentially flat surfaces of the upper teeth set at a slight angle to the horizontal. The intent in this concern is to eliminate occlusal deflective contacts and, thus, provide greater stabilization of the dentures.

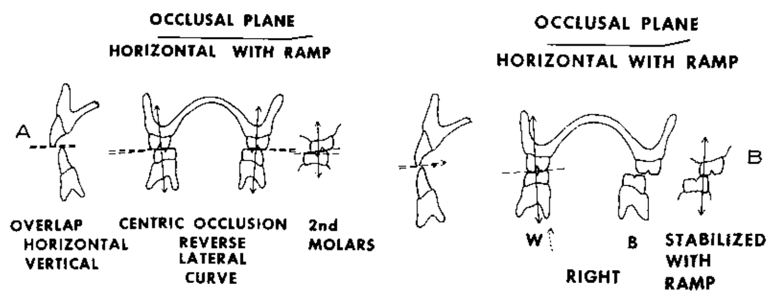


Fig. 4. *(A)* An arrangement of teeth with a reverse lateral curve through the first molars will direct contact forces toward the lingual side of the lower ridge and toward the buccal side of the ridge at the second molar ramp. *(B)* Gliding surfaces will direct contact forces toward the lingual side of the lower ridge on the workng side *(W)* and toward the buccal side of the ridge on the balancing side *(B)*, depending on the inclination of the second molar ramp.

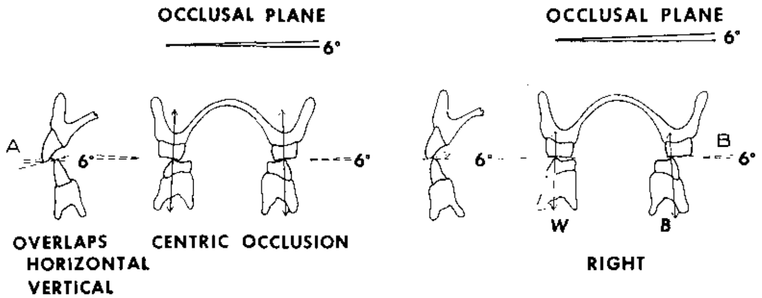


Fig. 5. In a linear occlusal concept the contact force would be directed toward the ridges and slightly toward the buccal side at the given inclination of 6 degrees. *(B)* From a right lateral movement, the directions of contact forces would be maintained toward the ridges and slightly toward the buccal side of the lower ridge.

## NONBALANCED OCCLUSIONS

(6) Fig. 6, A and B, depicts a concept as advocated by Pound *[1971]* which stresses the positions of the anterior teeth to preserve or re-establish the phonetic values of the patient in harmony with increased denture

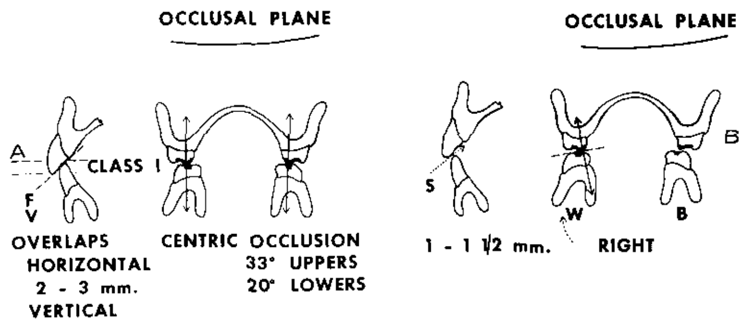


Fig. 6. *(A)* One of several combinations of posterior tooth designs is illustrated in which upper lingual cusps make contact in lower fossae and in which the contact forces are directed toward the ridges. Gold occlusal inlays help maintain the occlusal vertical dimension. *(B)* From a right lateral position, only the upper lingual cusps glide on low opposing inclines into enlarged fossae in the lower teeth. The buccal cusps on the working side are out of contact, and there are no balancing-side contacts. The contact forces on the working side are directed toward the lingual side of the lower ridge. Accurate retentive bases are indicated. This concept also uses phonetic sounds of "F," "V," and "S" for the placement of the anterior teeth before the posterior teeth are arranged.



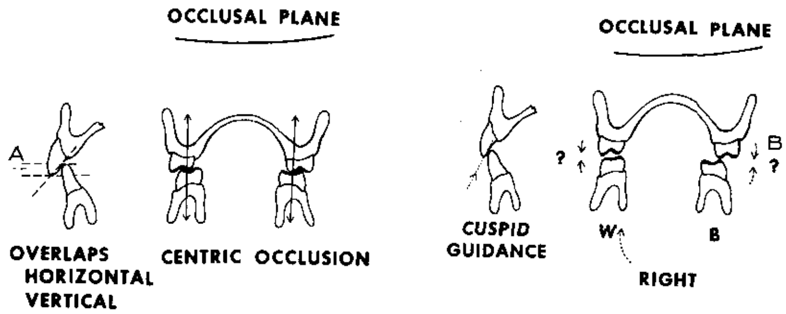


Fig. 7. *(A)* A concept which uses deep vertical overlaps, when indicated phonetically and esthetically, and anatomic posterior teeth with full gold occlusal surfaces is illustrated. The upper lingual cusps and lower buccal cusps contact opposing fossae, and the composite directions of contact forces are exerted toward the ridges. *(B)* From a right lateral position to centric occlusion, cuspid guidance disoccludes the posterior teeth until occlusal contact is made in centric occlusion. Accurate retentive denture bases are a requirement in this concept.

stability and efficiency with the chewing cycle. Several characteristics of this concept are the incorporation of sharp upper lingual cusps in opposing widened fossae of the lower teeth in centric occlusion, the reduction of the buccal cusps of the lower posterior teeth, and the elimination of deflective contacts by the use of occlusal adjustment wax on the completed dentures. In effect, the occlusion is lingualized by the elimination of contacts on the buccal cusps and by the anteroposterior arrangement of the lower posterior teeth so that their lingual surfaces are on or within the lingual side of a triangle from the mesial area of the lower cuspid to the sides of the retromolar pad. Partial occlusal metal inlays may be used to minimize wear on teeth and, thus, help maintain the vertical dimension of occlusion.

(7) Another concept utilizes a 33 degree cusp form with full occlusal gold surfaces (Fig. 7, A and B).* The anterior teeth are set to the requirements of phonetic values. Extreme vertical overlaps producing cuspid guidance are frequently used, resulting in disocclusion of the posterior teeth away from centric occlusion. Characteristic of this concept is the use of pantographic tracings and the transfer of these recordings to an instrument to eliminate all potential deflective contacts in the arrangement of the posterior teeth.

(8) A contemporary occlusal design which is used extensively utilizes nonanatomic teeth in a straight occlusal plane, usually horizontal, when

*Aull, A. E.: Personal communication.

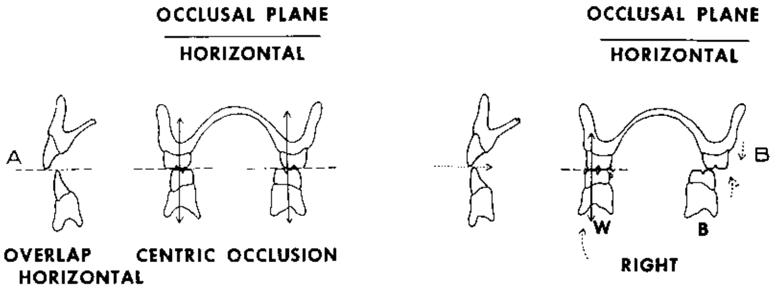


Fig. 8. *(A)* Nonatomic posterior teeth in a flat plane with a minimal vertical overlap in the anterior region is a widely used concept. The contact forces are directed toward the ridge bilaterally in centric occlusion. *(B)* From a right lateral position to centric occlusion, only the buccal cusps on the working side *(W)* contact if the path of the condyle is not parallel to the occlusal plane. Tilting of the bases and shear lateral forces may result if extreme gliding occlusal contacts are made *(B)*.

the casts are mounted horizontally in an instrument (Fig. 8, A and B). All-porcelain or all-plastic posterior teeth may be used, or combinations of posterior teeth of porcelain upper and plastic lower teeth, or metal shearing blades may be incorporated in a block of the upper posterior teeth occluding against lower porcelain teeth as advocated by Hardy *[1951]*.

(9) Occlusal pivots were advocated by Sears *[1956]* (Fig. 9, A and B). The primary concerns are that the mandible be placed in equilibrium by maintaining the load in the molar regions, that the procedure protects

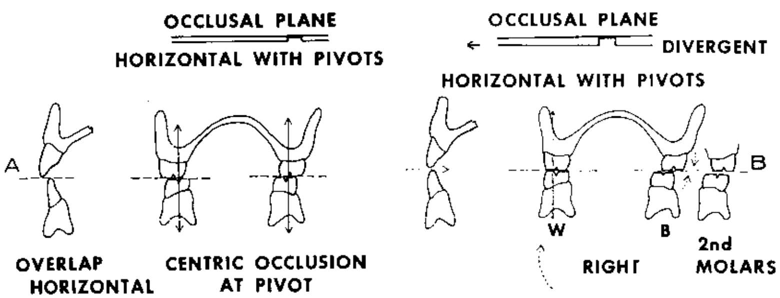


Fig. 9. *(A)* Pivoting in the posterior region of a flat occlusal plane has been used to alleviate temporomandibular joint symptoms. Contact forces are directed toward the ridges in centric occlusion. *(B)*From a right lateral position to centric occlusion, only the working-side pivot will contact if the path of the condyle on the balancing side *(B)* is not parallel to the occlusal plane.



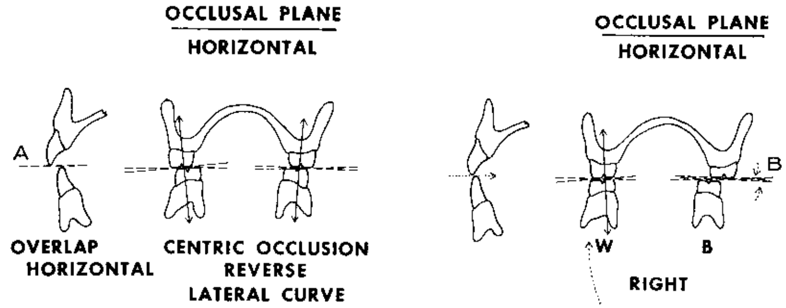


Fig. 10. *(A)* A concept which utilizes a flat anteroposterior occlusal plane and a reverse lateral curve is not used extensively. Contact forces are directed toward the lingual side of the lower ridge in centric occlusion. *(B)* Occlusal contact is maintained in a movement from a right lateral position to centric occlusion on the working side *(W)* only, with contact forces directed toward the ridges. *(B)*, Balancing side.)

the temporomandibular joints against injury, and that the stresses are also reduced in the anterior regions of the ridges in anticipation of tissue maintenance.

(10) A reverse lateral curvature in the occlusal arrangement is used infrequently (Fig. 10, A and B). The mounted casts and the occlusal plane are on a horizontal plane in the instrument without a posterior ramp which results in a nonbalanced occlusion in eccentric positions. One type of this occlusal pattern was developed by Kurth *[1954]* and consisted of posterior tooth blocks in series of four teeth which were arranged on a flat anteroposterior occlusal plane with a reverse lateral curve (reverse of Wilson curve).

## CONCLUSIONS

(1) Ten occlusal concepts with different occlusal arrangements for complete dentures have been reviewed.

(2) Five of these designs are in the balanced concept, and five in the nonbalanced concept.

(3) Contact forces which are transmitted to the basal seat areas of dentures vary with different occlusal patterns and designs.

(4) Efficiency of the teeth in triturating food in mastication is a factor which also needs evaluation relative to maintenance of supporting tissues.

(5) A few long-term investigations are in progress to evaluate statistically (a) several tooth forms and compare them and (b) the use of one tooth form with different clinical procedures.

(6) It is conceivable that more than one occlusal design can provide satisfactory denture service and fulfill the requirements of esthetics, function, and maintenance of supporting tissues.

## SUMMARY

Occlusal designs and their resulting functions are of concern to the dentist so that loss of the remaining tissues of the mouth, which may be attributed to the occlusion, can be minimized. This is difficult to assess since living tissues change and physiologic tolerances vary. More long-term statistical investigations are necessary to compare the various occlusal designs so that more definable guidelines may evolve. Until such guidelines are available the dentist must rely on his clinical experience and clinical judgment to select the occlusal design or designs of his choice in the treatment of complete denture patients.

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# SECTION REPORT

## INTRODUCTION

Between the years 1840 and 1970, 333 United States Patents were issued which cover dental articulator designs *(House, 1971)*. There is a need to correlate articulators to articulation. A chart was designed to bridge between the review of the literature for this Section, by Frank V. Celenza, and the deliberations of the Workshop contributors.

## DEFINITIONS

As some terms defined in the Glossary of Prosthodontic Terms *(1968)* were not acceptable for application by this Section, it was necessary to define several terms for convenience:

*Articulator.* A mechanical device to which maxillary and mandibular casts are attached.

*Cast relator,* (as described in the literature review). Same as articulator.

*Balanced centric occlusion.* Bilateral simultaneous centric tooth contact.

*Balanced eccentric occlusion.* Bilateral simultaneous eccentric tooth contact.

*Eccentric nonbalanced occlusion.* Lack of equal distribution of weights and/or quality between two sides, such as protrusive nonbalance, bilateral nonbalance, and working side nonbalance.

*Pantographic record.* Three-dimensional graphic tracings of the patient's pathways of condyle movements.

*Stereographic registration.* A molded and engraved record of condyle pathways. It records border form and intraborder form created as pathways of condyle movements.

## ARTICULATORS AND ARTICULATION

The accompanying chart is designed to list several methods for complete denture construction. Articulator design, records required, and occlusal



| ARTICULATOR DESIGN | RECORDS REQUIRED | OCCLUSAL SCHEME |
|---|---|---|
| Class I, Subdivision A. Simple holding instruments capable of accepting a single static registration. Vertical motion is possible but only for convenience. Those instruments that do not relate to the temporomandibular joint. | Centric jaw relation record. | 0° linear |
| Class I, Subdivision B. Simple holding instruments capable of accepting a single static interocclusal registration. Vertical motion is possible but only for convenience. Those instruments that do relate to the temporomandibular joint. | Centric jaw relation record plus face-bow. | 0° linear |
| Class II—Instruments that permit horizontal as well as vertical motion but do not orient the motion to the temporomandibular joint. | | Any occlusal scheme desired. |
| Subdivision A. Eccentric motion permitted is unrelated to mandibular motion. | Centric jaw relation record. | |
| Subdivision B. Eccentric motion permitted is based on theories of arbitrary motion. | Average settings on articulator, these are average setting articulators. | |
| Subdivision C. Eccentric motion permitted is determined by the patient using engraving methods, and here we would not use average settings, but would need centric jaw relation record only | Centric jaw relation record. | |
| Class III, Subdivision A. Instruments that simulate condyle pathways by utilizing averages or mechanical equivalents for all or part of the motion. These instruments allow for joint orientation of the casts and may be arcon or nonarcon instruments. Instruments that accept static protrusive registrations and use equivalents for the rest of the motion. | Centric jaw relation record<br>Face-bow record<br>Protrusive interocclusal registration | Any occlusal scheme desired. |

| ARTICULATOR DESIGN | RECORDS REQUIRED | OCCLUSAL SCHEME |
|---|---|---|
| Class III, Subdivision B. Instruments that simulate condyle pathways by utilizing averages or mechanical equivalents for all or part of the motion. These instruments allow for joint orientation of the casts and may be arcon or nonarcon instruments. Instruments that accept static lateral protrusive registrations and use equivalents for the rest of the motion. | Centric jaw relation record<br>Face-bow record<br>Protrusive interocclusal registration<br>Lateral interocclusal registration | Any occlusal scheme desired. |
| Class IV, Subdivision A. Instruments that will accept three-dimensional dynamic registrations. These instruments allow for joint orientation of the casts. The cams representing the condylar paths are formed by registrations molded and engraved by the patient. These instruments do not allow for discriminatory capability. | Centric jaw relation record<br>Face-bow record<br>Stereograph record | Any occlusal scheme desired. |
| Class IV, Subdivision B. Instruments that will accept three-dimensional dynamic registrations. These instruments allow for joint orientation of the casts. Instruments that have paths that can be angled and customized either by selection from a variety of curvatures, by modification or both and allow for discriminatory capability. | Centric jaw relation record<br>Face-bow record<br>Pantograph record | Any occlusal scheme desired. |

schemes possible are listed for each method.

For all types of occlusal schemes used in complete denture construction, Class III and Class IV articulators satisfy most completely the means for providing individualized denture articulation for the majority of patients. The more complete and detailed the eccentric registrations used, the less corrective adjustment may be required in the completed prosthesis.

Some instruments in the Class III category are of the nonarcon type.



It should be pointed out that the arcon design is preferable in some ways to the condylar-type of articulator.

When using condylar-type articulators, it is important to note that when an interocclusal eccentric record is used to set the condyle guides, an inconsistence can occur in the angle between the fossa and the occlusal plane. This inconsistency can be compensated for by altering the condyle guide settings. This accommodation procedure is recommended when using any nonarcon articulator.

## RECORDS

Records required for each type of articulator have been shown in the chart. Some position statements are included here.

**FACE-BOW.** The selected axis face-bow (sometimes termed an arbitrary axis face-bow) is adequate for the fabrication of complete dentures provided a minimal thickness interocclusal record is used when centric and eccentric jaw relations are recorded.

**JAW RELATION RECORDS.** Two methods for recording centric jaw relation are commonly used: **a.** graphic method using a central bearing point designed to distribute forces equally over the denture seat area, and **b.** an interocclusal wax (or other soft material) into which the patient's jaw is closed. With the central bearing point method, it is difficult to place the bearing point in the center of both the maxillary and mandibular arches. If the central bearing point is not centrally located, tipping of the bases can occur. The interocclusal record obtained by tactile guidance of jaw closure may minimize tipping of the bases.

There are varying philosophies as to the amount of pressure desired when interocclusal records are made. One group recommends minimal pressure whereby the only pressure supported by the denture bases would be the weight influence of the recording material used. Another group chooses to select various pressures which are programmed by the interocclusal recording material used. This could be termed the selective pressure method and this group believes that this seating of the recording bases simulates the pressure occurring when using the complete dentures. Presently no single method or philosophy can be recommended. Record making is a learned skill and the method used should be individually chosen.

**ECCENTRIC RECORDINGS.** There are various ways in which this can be accomplished, such as with interocclusal records, graphic methods, pantographic recordings, and stereographic records. All of these methods are subject to variability and may be influenced by denture base movements, material variables, operator inconsistencies, patient coordination and cooperation, and dysfunction in the masticatory system. It is desirable that all records be reproducible, but reproducibility does not imply correctness. The fact that these errors are inherent in all methods does not negate the necessity for striving for the greatest accuracy in all procedures.

It is the opinion and clinical experience of many that pantographic registrations can be reproduced for edentulous subjects. This we accept, even though it has yet to be established in the literature.

**CENTRIC JAW RELATION.** Centric jaw relation is a useful reference position. The entry or exit from this position must not be inhibited. Therefore, an area anterior to centric jaw relation, where maximum intercuspation can occur, may be provided. The limits of this area have not been clearly defined at this time.

## CONCLUSIONS

Further investigation in all areas is required to establish the accuracy desired for complete denture construction. We recommend that the following items be included in undergraduate and graduate dental curriculums.

**UNDERGRADUATE AND GRADUATE TEACHING.**

1. Greater emphasis and use of existing diagnostic aids, such as temporomandibular joint radiographs, in complete denture planning and/or treatment phases.
2. In order to promote better understanding of occlusal designs, and to coordinate them to oral physiology, it is recommended that the following be included in dental school curriculums: **a.** graphic registration of mandibular movements, **b.** coordination of graphic registrations to occlusal morphology, and **c.** use of various prosthetic tooth occlusal schemes of articulation.

**FUTURE RESEARCH.** We recommend longitudinal research projects to be done in depth where indicated, and that dental schools be solicited for active participation. We specifically recommend the following projects.

1. Investigate the value of temporomandibular joint radiographs as aids to clinical diagnosis, treatment, and correlation to other research.



2. Determine the most acceptable location, in the horizontal, frontal and vertical planes, of posterior teeth in maximum occlusal contact position.
3. Investigate denture stability during masticatory function and correlate the data to tooth forms, and occlusal schemes using: **a.** average value articulators, **b.** positional jaw registration programmed articulators, **c.** pantographically programmed articulators, and **d.** engraved jaw registration, programmed articulators.
4. Investigate the occlusal contact sensitivity of proprioception of complete denture wearers.
5. Investigate the relationship of different articulator types and occlusal schemes as they affect the volumetric and area changes of the supporting soft tissue and osseous structures.
6. Investigate the effect and accuracy of tissue contact of complete dentures at the delivery and post-insertion phases of denture therapy with occlusal adjustments or tooth contact.
7. Investigate the duplicability of pantographic tracings and articulator settings in the edentulous patient. The effects of such variables as secured bases and clutches as opposed to bases and clutches held in position by a light biting pressure might also be studied.
8. Investigate the frequency of centric relation—centric occlusion contact positions using a number of methods simultaneously (i.e. radiographs, telemetry, electromyography and cinefluoroscopy.).

This is a consensus report of the Section.

Respectfully submitted,

Allen A. Brewer, *Chairman*
James E. House, *Secretary*
Frank V. Celenza, *Reviewer*
William E. Kotowicz, *Reviewer*
Alfred H. Geering, *Reviewer*
Heinz O. Beck, *Reviewer*
Daniel H. Gehl
Albert Gerber
Niles F. Guichet
Daniel Isaacson
Charles S. Paraskis
Lawrence A. Weinberg
Harvey H. Wipf
Joel M. Zahler, *Section Assistant*

**References**

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# DISCUSSION OF REPORT

Following Brewer's reading of the Section report, Celenza moved for its acceptance. The motion was seconded by Isaacson and passed by a voice vote.

## RE: DEFINITIONS

Ramfjord objected to the definition of a pantographic record—"a three-dimensional graphic tracing of the patient's pathways of condyle movements." He indicated that a pantograph does not directly trace the pathways of the condyle movement. Rather, it is an *extended* tracing—not the tracing of the actual movements of the condyle. Celenza responded for the Section members and agreed to the suggested correction.

Zander requested further explanation by the Section members regarding the definition of a stereographic registration. The report read that a stereographic registration is "a molded and engraved record of condyle pathways. It records border form and intraborder form created as pathways of condyle movements." Zander asked what was meant by border form? Border of what?

Wipf indicated that they were referring to the extreme border movement and that it is registered as a wall rather than a line. Zander cited Posselt's Ph.D. thesis as a reference for border movements as three-dimensional movements and asked if border form also referred to a three-dimensional registration. Wipf responded affirmatively and further stipulated that it should be recorded at a selected vertical. Ramfjord requested a poll of the Section members to indicate their acceptance of this clarification. The Section accepted this change for the record.

Graf disagreed with the definition of eccentric nonbalanced occlusion as read and indicated that the definition of occlusion refers to contact. He suggested replacing the word weight with the word contact, making the definition read, "lack of equal distribution of contact and/or equality between two sides such as protrusive nonbalance, bilateral nonbalance, and working side nonbalance." Brewer responded for the Section by agreeing to the change.



## RE: ARTICULATOR CLASSIFICATION

Boos asked which articulator design was being recommended when the generated occlusal path or functional path methods were used. Brewer indicated that the articulator design suggested was Class II, Subdivision C, where the eccentric motion permitted is determined by the patient, using engraving methods.

Rudd asked if a face-bow should be added under records required for the articulator Class II, Subdivision C, while other instruments that use the engraving technique require the face-bow, and are classified under Class IV, Subdivision A.

## RE: INCONSISTENCE IN ANGLE BETWEEN THE FOSSA AND THE OCCLUSAL PLANE

Koper requested clarification regarding this area. Brewer indicated that when using condylar-type articulators it is important to note that when an interocclusal eccentric record is used to set the condyle guides, an inconsistence can occur in the angle between the fossa and the occlusal plane. However, this inconsistency can be compensated for by altering the condyle guide settings.

## RE: LINEAR OCCLUSION SCHEME

Yurkstas requested a definition for zero degree linear occlusal scheme. Brewer indicated that the linear occlusal scheme referred to the setting of teeth on a flat plane—parallel to some reference plane.

## RE: JAW RELATION RECORDS

Woelfel requested clarification regarding the pressure used during the registration of jaw relation records. Brewer replied that there are as many ways to accomplish registrations as there are dentists, and that the Section members felt that no single method or philosophy could be singled out for recommendation. He said that, "record making is a learned skill and the method used should be individually chosen."

Ramfjord felt that when recording centric relation, the operator has to physically guide the closure of the patient's jaw rather than allowing the patient to close without guidance.

## RE: CHARACTER OF CENTRIC CONTACT POSITION

House indicated that what the Section members called "the character of centric contact position" required further discussion. Celenza stated that the Section members agreed that all contacting positions are areas that may vary in size around the recorded position. The dimensions of the areas could not be defined, but it was agreed that they should not be what would normally be referred to as a point.

## RE: TEMPOROMANDIBULAR JOINT RADIOGRAPHS

Weinberg suggested that before-and-after temporomandibular joint radiographs be taken for all patients who receive complete mouth prosthesis, either fixed or removable, in order to substantiate clinical findings. He felt that this would provide information correlating the clinician's results with the newly developing understanding of the temporomandibular joint radiographs and their use. Weinberg added that this will provide a measure of safety in the event of the unfortunate need of legal proceedings. Ramfjord requested documentation to support these comments. Weinberg discussed the subject further, but did not present documentation.

SECTION IV

# Occlusal Patterns and Tooth Arrangements

## Review of Literature

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## Section Report

## General Assembly Discussion

# REVIEW OF LITERATURE

*KRISHAN K. KAPUR*

## HISTORICAL BACKGROUND

The search for the ideal occlusal form has been going on for almost two centuries. This long search has been prompted by the need to identify an ultimate occlusal form that provides maximum denture stability and masticatory efficiency without sacrificing esthetics or the underlying bone. The emphasis on stability or efficiency has varied with each designer. All manner of designs were contrived—some based on emerging scientific knowledge and others developed through hours of trial and error. Whether using scientific or empirical approaches, designers were also limited by the type of materials then available.

In the 19th century Balkwill *(1866)* and Bonwill *(1899)* described occlusal forms developed by the modification of available conventional teeth. The systematic approach to designing better occlusal forms to permit "anatomical" articulation came in the early twentieth century. Dr. Alfred Gysi is singled out by dental historians and clinicians alike for his work in systematizing methodology.

Clapp *(1914)* reviewing the work of Gysi, mentioned that Gysi identified many gross deficiencies in the existing teeth which required extensive grinding before they had any semblance of anatomic form. The teeth in use were essentially copies of worn natural forms and could almost be considered nonanatomic. The resulting dentures presented broad occlusal surfaces without the ridges. In their design little or no thought was given to achieving occlusal articulation on movable denture bases.

Gysi *(1910, 1921a, 1921b, 1929a, 1929b, and 1931)* was also aware that only a limited amount of occlusal pressure could be tolerated by denture wearers. Therefore, the denture teeth required even more efficient designs based on engineering principles so that proper mastication could be attained with minimum pressure. He established averages of several parameters necessary for simulating the mandibular movements on a mechanical device. He studied the relative influence of several factors such as the location of the horizontal axis, the occlusal plane, the condylar inclination, and the inclination of incisal guidance on the occlusal form and occlusal articulation. Using averages of 33° condylar inclination and 33° incisal guidance, he engineered occlusal surfaces of 33° teeth which he presented to the profession as "Trubyte" teeth. These designs included the incorporation of facets that would permit not only a balanced occlusion, but also efficient comminution of food. Fossae and sulci were added at appropriate locations so as to allow escape of the ground food during mastication. It has been claimed that the design of occlusal forms of Trubyte teeth permitted the bicuspids to perform the action of trapping, cracking, and tearing food and the molars to perform the action of cutting and grinding as a mortar and pestle. It was stated that these teeth could be adapted to different condylar inclinations and incisal paths by milling the articulated sets together with carborundum paste.

Although these teeth provided a workable design in many instances, problems were encountered for using such teeth in cases with disproportionate jaw relationships. This difficulty prompted Gysi *(1927)* to develop occlusal forms for crossbite arrangements. This was accomplished by reducing the size of occlusal surfaces as well as by eliminating the buccal cusp of the maxillary teeth.

The Trubyte 33° teeth as well as the crossbite teeth were chiefly designed to develop a balanced occlusion in complete dentures. Balanced occlusion includes an ideal centric closure and bilateral balance in eccentric relations through simultaneous gliding contacts between the inclined planes on the working side as well as on the balancing side. This type of articulation is attainable on the articulator, and has been explained on the basis of geometry, cinematics, and mechanics described by Hanau *(1923, 1926, 1930, and 1931).*

Hanau *(1926, 1930, and 1931)*pointed out the interrelationships of five major factors; i.e., condylar guidance, incisal guidance, tooth alignments, relative cusp height, and position of the triangle of orientation. His analysis of these principles, involved in aligning teeth into balanced articulation, resulted in listing forty laws (ten groups of four each), each group with a main law and its three transformations. These were presented in a diagrammatic fashion as the "Articulation Quint." It is difficult, however, to maintain balanced occlusion in the mouth because of the continuous resorption of residual ridges, resulting in the shifting of denture bases. Occlusal interference, especially in the anteroposterior relationships, was often seen and demanded continuous occlusal adjustment. Some clinicians believe that extreme cuspal interlocking of anatomic teeth may induce trauma and cause excessive resorption of residual ridges.

Concern for ridge loss started a trend toward the development of the nonanatomic occlusal forms. The earliest design by Sears *(1928)* retained the lateral balance by maintaining buccal and lingual slopes of the maxillary teeth. However, it eliminated the anteroposterior cuspal inclines. It was further claimed that this design was also based on the principle of shearing the food rather than the grinding action of a mortar and pestle. This radical departure elicited considerable unfavorable response from the conservative members of the profession as well as from the manufacturers. It started a shift from the complete balanced occlusal concept towards the designing of occlusal forms which required no intercuspation. Because of the obvious differences in anchorage, and the manner in which natural and artificial dentures resisted forces, many clinicians began to accept nonanatomic forms *(Sears, 1952).*



This change in concept challenged the conventional thinkers to experiment and to try new ideas. Since 1930, we have gone through a period of increased interest in designing a variety of occlusal forms. Several principles of physics were considered in the design and arrangement of teeth. Moses *(1946, 1968)* indicated that improvement in denture efficiency and stability may be attained by reducing the area of the occlusal surface, centralizing the occlusal force on the residual ridge, and applying the chewing forces on a flat surface rather than on an inclined plane.

Moses *(1946, 1959)* and MacMillan *(1931)* derived information from animals as well as primitive and civilized human studies which aided in the search for the most efficient occlusal scheme for complete dentures. As a result of their studies many nonanatomic occlusal forms with different geometric patterns, metal inserts, and occlusal surfaces of varying buccolingual widths, have been offered to the profession, as have a number of new anatomic teeth and designs with varying cusp steepness. The history of tooth form has been reviewed by Hardy *(1951)*, Sears *(1953)*, and Rapp *(1954)*.

## CLASSIFICATION OF TOOTH FORMS

Boucher, C. O. *(1953)* classified posterior teeth as anatomic or nonanatomic. Yet, an appropriate classification should take into consideration not only the configuration of the occlusal surface, but also the purpose it serves in articulation. The available occlusal forms can thus be classified into three distinct groups: **a.** anatomic teeth, **b.** semianatomic teeth, and **c.** nonanatomic teeth.

**ANATOMIC TEETH.** Teeth with cuspal inclination of 30 degrees or more can be classified in this group. In the Glossary of Prosthodontic Terms *(1968)*, anatomic teeth are defined as "artificial teeth which more or less duplicate the anatomic forms of natural teeth. Teeth which have notably pointed or rounded eminences on the masticating surfaces and are designed to occlude in the sulci of the teeth of the opposite denture or dentition." This definition refers primarily to occlusal configuration and fails to give the purpose served by this configuration in articulation.

The anatomic tooth permits the harmonious relationship between the occluding surfaces in centric and eccentric positions, which may be established through the use of registration of condylar path positions and the incisal guidance. The major advantage of this form is to allow the establishment of mechanically and/or physiologically balanced occlusions. In many general practices, this tooth form is used primarily to achieve centric occlusion wih maximal intercuspation. In too few practices is an effort made to develop balance in eccentric jaw motions or positions.

Many men have carved anatomic occlusal forms by using natural teeth as models. The designs of Gysi *(1929)*, and Pilkington and Turner were engineered with mathematical information derived from extensive research and experimentation *(The Dentists' Supply Company, 1953)*. It is claimed by the manufacturer that the Pilkington and Turner 30° teeth provide freedom from a cusp locked occlusion and prevent interference in masticatory movements; i.e., they allow the development of a small area rather than a point for centric occlusion. This feature was incorporated in the design by relieving the protrusive and transverse facets of teeth that were machine cut to a close tolerance. Another feature claimed in this design is a 5° buccal slope in bicuspids to enhance esthetics. The following specifications were employed by the manufacturer for Pilkington and Turner teeth *(The Dentists' Supply Company, 1953, 1966)*.

"The tooth design should provide:

1. Average protrusive jaw movements, thus requiring a minimum of cusp change to fit steep or shallow angles.
2. A transverse or occlusal pattern equal to, or exceeding, the composite maximum lateral Gothic arch angles found in average normal mandibular movements.
3. Opening angles of such degree that the dentures are held firmly against the ridges by the force exerted in mastication.
4. Primary cusp planes which run parallel to corresponding planes in the opposing teeth in all movements.
5. Primary cusp planes which harmonize, not only with opposing cusp planes, but also with the average angles of the greatest percent of jaw movements.
6. Ample grooves for all opposing cusps to slide through in all movements.
7. Freedom from restraint and interference in all intermediate masticating movements in normal average jaw movements.
8. Freedom from locked occlusion.
9. Occlusal cutting facets sharp enough to masticate food without undue pressure.
10. Primary forms which require only a minimum of hand carving to create superior anatomical shapes without materially altering the cusp planes."



**SEMIANATOMIC TEETH.** Teeth with shallow cusps and less steep inclined planes than those of the Trubyte 30° cusp teeth can be included in this category. A good example of this type of occlusal form is the Trubyte 20° cusp teeth and Sears channel teeth. Schuyler *(1934, 1952)*, and Trapozzano *(1952, 1957)*, report semianatomic forms that seem to have evolved as a compromise for those who believed in basic cusp form for chewing efficiency and in cusp balance for denture stability, but were concerned with the lateral torque that might be produced by high cusps and steep inclined planes of anatomic teeth. Their use was made common by Schuyler *(1952)*, who pointed out that functional harmony with the inclines of the glenoid fossa can be achieved with cusp teeth of less steep inclines by reducing the incisal guidance, which is the only independent factor of all the factors governing articulation. It has more influence on cusp inclines than the condylar guidance. These forms thereby offer some semblance of the anatomic form, but provide features that help to negate some of the criticism levied against anatomic teeth.

**NONANATOMIC TEETH.** All teeth with occlusal forms that have no resemblance to anatomic teeth and offer occlusion without intercuspation are included in this group. The Glossary of Prosthodontic Terms *(1968)* includes semianatomic teeth in this category and defines nonanatomic teeth as "artificial teeth so designed that the occlusal surfaces are not copied from natural form but rather are given form which in the opinion of the designer seem more nearly to fulfill the requirements of mastication, tissue tolerance, *etc.*" This definition gives the impression that nonanatomic designs result in better masticatory function than do anatomic teeth. Proponents of the anatomic teeth question this interpretation. The nonanatomic group includes all occlusal forms that are termed zero degree, or occlusal forms having no cusp angles with respect to the horizontal.

Hall *(1931)*, French *(1935)*, Hardy *(1942)*, and Myerson *(1957)* presented designs with major differences either in the geometric occlusal pattern and/or in the buccolingual width of the teeth.

Hardy *(1951)*, Moses *(1954)*, and Sosin *(1961)* described occlusal designs using metal inserts on the occlusal surface to provide better cutting action as forms of nonanatomic teeth. The following specifications were developed and listed by Sears *(1952)* in his research for an efficient nonanatomic occlusal form.

"1. The working occlusal surfaces should be void of cusps or inclined planes that might hinder the free horizontal gliding of opposing surfaces as the alveolar ridges resorb or as the mandible carries the teeth into protrusive occlusion.

2. The working occlusal surfaces should have no inclined planes (or only low ones) that might hinder the free horizontal gliding of opposing surfaces as the mandible carries the teeth laterally.
3. The working occlusal surfaces should be so incorporated that more than 50 percent of such surfaces can be placed lingual to the ridge center, with 100 percent as the ideal.
4. The working occlusal surfaces should be so incorporated that the greatest load can be applied at a desired mesiodistal point. This provides against front-to-back teetering.
5. The working occlusal surfaces should be so incorporated that they can be placed parallel with the underlying alveolar ridge as seen from the side.
6. The area of the combined working occlusal surfaces should be in proportion to the supporting value of the weaker of the two denture foundations. Weaker foundations require smaller occlusal surfaces. This would not require a large number of molds if Specification 7 is met.
7. The teeth should be so designed that they can be altered by grinding without losing their mechanical or esthetic advantages. This has special reference to the possibility of reducing, either buccolingually or mesiodistally, teeth that may be slightly too large.
8. There should be no wells, traps, boxlike cavities, or hollows into which food can pack. All major depressions should be provided with adequate escapeways.
9. The working occlusal surfaces should be so formed that there will be no necessity to leave spaces distal to the proper cuspids, or to narrow the lower eight anterior teeth as is done with the so-called anatomic teeth, where less-than-average horizontal overlap is used. This requirement is met essentially by observing Specification 1.
10. Those parts of the occlusal surfaces on which it is desired to maintain the principal load (usually the first molars) should be composed of a more wear-resistant material than the other parts. This tends to assure automatic occlusal adjustment under changes due to ridge resorption and condyle migration.
11. Balancing occlusal surfaces should be so incorporated that they can be made to maintain contact on the right and left sides as the mandible carries the teeth into left and right lateral occlusions. Such lateral balancing occlusal surfaces can be placed conveniently on the upper first molars or the lower second molars.
12. The balancing occlusal surfaces should be used only for balancing. This means that these surfaces should not be used also for working occlusal surfaces as is the case with so-called anatomic teeth.



13. Right and left balancing occlusal surfaces should be so incorporated that they can be made to maintain contact simultaneously on the right and left sides as the mandible carries the teeth into protrusive occlusion.
14. All balancing occlusal surfaces should be adjustable independently of the buccal, lingual, working, and sub-occlusal surfaces. This is in contrast to the so-called anatomic scheme in which balance is obtained by tilting the entire tooth and thus disturbing the angles of the other surfaces.
15. Each balancing occlusal surface should be adjustable independently of all other balancing occlusal surfaces. This requires a minimum of four units: (1) right for left lateral, (2) left for right lateral, (3) right, and (4) left protrusive occlusion.
16. The buccal surfaces should be so incorporated that they make satisfactory contact with the cheeks without contributing to cheek biting.
17. The visible buccal surfaces should simulate the forms of natural teeth.
18. The lingual surfaces should be so incorporated that they make satisfactory contact with the tongue in eating and speaking without contributing to tongue biting.

Dentists who do not believe in placing nonanatomic teeth on an inclined plane for achieving balanced occlusion in eccentric relationships will ignore specification numbers 11 to 15 pertaining to occlusal balance."

## THE ADVANTAGES OF ONE OCCLUSAL FORM OVER ANOTHER

The literature is cluttered with statements presenting the pros and cons of the various types of occlusal forms. Often these claims are based upon empirical judgment, witness such statements as, "cuspless teeth forgive many of the sins of inaccuracy over which we have no control" *(Collett, 1955)*, and "the faults attributed to cusp teeth are due to misarrangements" *(Schuyler, 1951)*. Not unexpectedly, opinions reflect the philosophy and training received during undergraduate or graduate education. Frequently, views remain set even though contradicted by objective studies.

Advocates of different occlusal forms *(Kimball, 1954; Wiland, 1964; De Van, 1945; Hickey, Boucher, C.O. and Woelfel, 1962; and Swaggart, 1957)* claim that their forms are less traumatogenic and help to control the rate of resorption of residual ridges. Often the disadvantages of one form are quoted as the advantages of the other and *vice versa*, *(Schuyler, 1935; Friedman, 1964; Kurth, 1954; and Moses, 1952)*.

The advantages and disadvantages of anatomic and nonanatomic occlusal forms described by various authors are presented realizing that most claims cannot be supported with sound scientific data *(Christensen, 1958; De Van, 1935; Friedman, 1951; Hughes, 1951a, 1951b; Jankelson, 1962; Jones, 1958, 1962; Kurth, 1962; Landa, 1960, 1962; Monson, 1922; Ortman, 1971; Payne, 1957; Pleasure, 1938; Porter, 1952; Sauser, 1957; Schlosser, 1928; Sears, 1951, 1960; Shanahan, 1958; Soltis, 1956; Stansbery, 1938; Terrell, 1951a, 1951b; Trapozzano, 1957; Villa A., 1959a, 1959b; Wehner, Hickey and Boucher, C.O., 1967; and Young, 1962).*

## ANATOMIC TEETH.

### ADVANTAGES OF ANATOMIC TEETH.

1. The cusp teeth can penetrate food more easily; therefore, they require less chewing force to comminute food and are considered more efficient for this purpose.
2. Cusp teeth can be articulated in harmony with the tempormandibular joint and the muscles of mastication.
3. Cusp teeth resist the rotation of denture bases through the interdigitation of cusps on the working side.
4. Cusps offer better esthetics and their resemblance to natural teeth may give a psychological advantage in mastication.
5. The interdigitating cusps of anatomic teeth provide a guide for proper jaw closure. It makes chewing more nearly vertical thus minimizing the lateral component in the normal chewing cycle.
6. Cusp teeth cause less trauma to underlying structures and offer greater comfort and longer usefulness.

### DISADVANTAGES OF ANATOMIC TEETH.

1. Cusp teeth have little tolerance in their articulation and, therefore, require an exacting technique, a complex adjustable articulator, and precise jaw relationships that are difficult, if not impossible, to register accurately on tissues that are movable.
2. The opponents of anatomic teeth frequently claim that cusp teeth produce lateral torque in eccentric occlusal contacts and may be more traumatogenic than noncusp teeth.
3. Adjustment of anatomic occlusion can be properly accomplished on an instrument, rather than intraorally, and requires a remounting procedure.
4. The relining and rebasing of denture bases with cusp teeth is a much more difficult task.



## NONANATOMIC TEETH

### ADVANTAGES OF NONANATOMIC TEETH.

1. Nonanatomic teeth do not lock the mandible in one position and they permit the use of a simple, less time-consuming technique and articulator.
2. Nonanatomic teeth minimize horizontal pressures because of the absence of inclined planes, and subject the supporting tissues to vertical pressures, which are thought to be less damaging.
3. Nonanatomic teeth permit closure in more than one position and thereby, centric relation can be used as an area rather than a point.
4. Nonanatomic teeth adapt easily to Class II and Class III jaw relations.
5. Nonanatomic teeth accommodate changes in vertical and horizontal relations, which result from the gradual remodeling and reduction in the volume of residual ridges. Occlusal correction can be accomplished easily to compensate for such changes.
6. Nonanatomic teeth make relining and rebasing a simpler procedure.
7. Nonanatomic teeth improve denture stability by permitting proper centralization of the occlusal plane in relation to residual ridges.

### DISADVANTAGES OF NONANATOMIC TEETH.

1. Nonanatomic teeth are less efficient for mastication as they do not penetrate food effectively. Therefore, chewing forces are increased to achieve proper comminution of food.
2. Nonanatomic teeth often present inadequate food escapeways. Clogging of their occlusal surfaces with food results in reduced masticatory efficiency and increased chewing pressures.
3. Nonanatomic teeth are esthetically inferior to anatomic forms.
4. Nonanatomic teeth encourage a higher component of lateral or diagonal jaw movement during chewing and increase, rather than reduce, horizontal forces on denture bases.
5. Nonanatomic occlusal forms may introduce a negative psychological influence in terms of food penetrating ability.
6. Nonanatomic teeth, set on a curved plane for balanced occlusion, introduce the inclined plane and can cause skidding of the denture base.
7. Nonanatomic teeth, set on a curved plane, do not coincide with actual jaw movements and can result in tripping and excessive friction.

## ARRANGEMENT OF TEETH

*Arrangement of teeth* is defined in the Glossary of Prosthodontic Terms *(1968)* as: "the placement of teeth on a denture or temporary base with definite objectives in mind." It includes both the establishment of the plane of occlusion and the occlusal scheme.

It is apparent from the literature that a great deal of controversy centers around the exact location of the plane of occlusion and more specifically the location of the food platform. This controversy extends into all three dimensions of the location of the food platform, namely in its buccolingual, superoinferior, and anteroposterior inclination. All approaches claim to strive for optimum denture stability, efficiency, and esthetics. One reason for the widespread controversy may be the ease of control by which the dentist can change this factor in denture construction. The degree of freedom depends upon the desired occlusal scheme. The dentist who believes in nonbalanced occlusal scheme and/or in nonanatomic teeth enjoys a greater degree of freedom than do those who believe in balanced occlusion. The inclination and superoinferior position of the occlusal plane is adjusted to achieve balanced occlusion by those who strive for this objective.

Often the concepts put forth for the arrangement of teeth are explained on mechanical, anatomical, or physiological bases, which may or may not have any scientific evidence.

## BUCCOLINGUAL POSITION OF OCCLUSAL PLANE

Esthetics and phonetics are the two major considerations in the arrangement of anterior teeth. The anterior teeth may be placed anterior to the crest of the ridge to achieve proper facial support. The main controversy still lies in the area of establishing the proper location of the posterior teeth. Two approaches have been suggested in developing the buccolingual arch form in the bicuspid and molar areas.

**BUCCOLINGUAL ARCH FORM BASED ON MECHANICAL CONSIDERATIONS.** Clinicians who strive for maximum stability for the mandibular denture through mechanical principles believe that the teeth should be arranged on, or lingual to, the crest of residual ridges so that the forces of mastication are at right angles to the residual ridge *(Sears, 1948, 1957; and De Van, 1956)*. This location of the food platform has been challenged by others who feel that such a mechanical concept of arranging teeth violates the tongue space and accentuates the facial deformities. Pound *(1951)*, Lamie *(1956)*, Fish *(1952)*, Roberts *(1951)*, Neufeld *(1958)*, and Carlsson and Persson *(1967)* substantiate their criticism through evidence that shows the clinical residual ridge to be often lingual to the bony ridge in mandibles with extreme alveolar ridge resorption.

**BUCCOLINGUAL PLACEMENT OF TEETH IN THEIR NATURAL LOCATION.** The placement of teeth close to their natural location is believed to develop a more harmonious relationship between the tongue, teeth, and the cheeks. Such a location would improve mastication and keep dentures in position by the balanced actions of the tongue and cheeks during function. This key relationship of the tongue, teeth, and the median role of buccinator muscle in mastication has been discussed in some detail by Wright, C. R. *(1966)*. He also considers that the mandibular first bicuspid should be placed slightly buccal to the crest of the ridge. This location is crucial to its function in preventing the food from moving into the anterior part of the mouth during mastication.



Several methods have been suggested for the placement of teeth close to their natural locations. Lott and Levin *(1966)* use molding compound or other impression materials to develop arch forms by the action of the tongue and cheeks during sucking and swallowing motions. All three dimensions of the occlusal plane, or the location of the food platform, are established with this technique. Wright, C. R. *(1966)* places the occlusal plane at the midpoint of the primary mandibular denture supporting area, while Block *(1953)* positions the plane midway between the tongue and cheeks. The location so derived is usually buccal to the crest of the clinical residual ridge.

The proponents of the mechanical concept charge that placement of artificial teeth in their original location creates leverage which will be proportionate to the distance horizontlly from the ridge crest. They believe it will cause extensive denture movement during function and will lead to excessive resorption of the residual ridges.

## SUPEROINFERIOR POSITION OF OCCLUSAL PLANE

As with the buccolingual positioning of the occlusal plane, controversy also exists in establishing its superoinferior location. There are clinicians who seek mechanical advantage to achieve increased denture stability while others attempt to approximate its natural location to attain better function.

**SUPEROINFERIOR POSITION BASED ON MECHANICAL CONSIDERATIONS.** Sears *(1957)* and Pleasure *(1937)* claimed greater denture stability when the height of the occlusal plane was kept closer to the denture base having the less favorable ridge size and contour. A higher location of the occlusal plane increases the leverage of the mandibular denture and exerts greater pressure on the supporting tissues. The mandibular denture is often favored for the placement of the plane of occlusion because its smaller denture-bearing area and unfavorable ridge contour present more problems in terms of retention, stability, and tissue trauma than does the maxillary denture. De Van *(1956)* suggested placing the occlusal plane midway between the maxillary and mandibular ridges.

As the anterior height of the occlusal plane is influenced by the location of anterior teeth, it is not uncommon that denture esthetics is somewhat sacrificed by those who use nonanatomic teeth in their efforts to achieve greater denture stability.

**SUPEROINFERIOR POSITION BASED ON ANATOMIC CONSIDERATIONS.** Wright, Swartz, and Godwin *(1961)* and Pound *(1954)* believe that placing artificial teeth close to their natural superoinferior location achieves not only denture stability but improves masticatory function as well. This position permits the tongue and cheeks to manipulate and confine food more readily during mastication. A higher or lower position would interfere with the functional movements of these structures and would produce greater dislodging forces on dentures. Several anatomic landmarks have been suggested to ascertain the natural location of the occlusal plane in edentulous patients. Standard *(1957)* used the opening of the Stenson's duct and places the occlusal plane 6 mm. inferior to this landmark. Boucher, C. O. *(1964)* recommends that the occlusal plane terminate posteriorly at the distal border or at the distal half of the retromolar pad and anteriorly at the tip of the mandibular cuspid. Nairn *(1965)* relates the occlusal plane to the lateral border of the tongue.

## ANTEROPOSTERIOR INCLINATION OF OCCLUSAL PLANE

As with the other two dimensions, either mechanical principles or the use of anatomic landmarks to determine its natural location are followed in establishing the anteroposterior inclination of the plane of occlusion.

**ANTEROPOSTERIOR INCLINATION BASED ON MECHANICAL CONSIDERATIONS.** Many consider that during function, the maxillary and mandibular occlusal surfaces should be parallel to the underlying ridges to achieve maximum denture stability. Brudvik and Wormley *(1968)* feel that in the event the two ridges are not parallel, the plane of occlusion is kept parallel to the unfavorable ridge, which usually is the mandible. Some authors recommend inclining the occlusal plane anteriorly to favor a positive seating of the mandibular denture, and posteriorly to favor a positive seating of the maxillary denture. Similarly, curves in the buccolingual or anteroposterior directions are introduced in the food platform for positive seating of dentures constructed on unfavorable ridges *(Nagle and Sears, 1962; Boswell, 1951; and Shanahan, 1955)*. However, this mechanical approach to improve seating of one denture inevitably introduces the opposite effect on the seating of the other denture.

**ANTEROPOSTERIOR INCLINATION OF THE PLANE OF OCCLUSION BASED ON ANATOMIC LANDMARKS.** A number of anatomic landmarks have been used to determine the anteroposterior inclination of the occlusal plane *(Broomell, 1896; Gillis, 1933; Schlosser and Gehl, 1953; McCollum and Stuart, 1955; and Sloane and Cook, 1953)*. The following are the most commonly used landmarks:

1. Frankfort plane
2. Eye-ear plane
3. Axis-orbital plane
4. Ala-tragus line or Campers plane
5. Base of the nose to condylar head
6. Corner of the mouth to the lower border of the ear lobe
7. Nasal spine to hamular notch
8. Height of lower canine to distal half of retromolar pad
9. Parallel to the lower ridge but 2 mm. below the tip of the retromolar pad, and the plane never above the corner of the mouth anteriorly
10. Keratinized and nonkeratinized junction of the mucosa covering the lateral borders of the tongue



## SUMMARY

It is generally agreed that complete dentures with maximum stability and an occlusal scheme that directs functional stresses vertically onto the residual ridges helps to preserve denture-bearing tissues. However, there exists a widespread controversy as to the best method of achieving these objectives in denture construction. There are two approaches. The first is based on the application of the laws of statics for denture stability, while the second stresses the duplication of natural architecture for proper functioning of oral structures. Most dentists lean toward either one or the other of these two approaches in their selection of tooth patterns as well as in their arrangement of teeth. The advocates of applying mechanical principles for maximum mandibular denture stability recommend that posterior teeth be situated according to three specific positions: **a.** lingual to or on the crest of the mandibular ridge, **b.** parallel to the flat portion of the posterior mandibular ridge on either side, and **c.** near the mandibular ridge. Proponents of these principles believe their approach results in greater denture stability, thereby protecting the residual ridges.

This "mechanical concept" is criticized by many who feel it impairs mastication, exaggerates facial deformities, and/or phonetic and esthetic complications. These critics stress the role of the facial and tongue musculature in achieving desired denture stability and function. Therefore, they prefer that the occlusal plane be located as close as possible to its original (natural) position. This position permits the cheeks and tongue to be most effective in deglutition, speech, and mastication. It is further contended that esthetics will be enhanced.

The advocates of the mechanical principles respond that when teeth are replaced so as to achieve the natural position, especially in cases with resorbed ridges, problems ensue. They cite, for example, that excessive leverage on the mandibular denture frequently results in trauma to the underlying tissues.

## RESEARCH ON PLANE OF OCCLUSION

From a review of dental literature, it is quite clear that despite all the controversy and subjective arguments, there is no substantial research to support one position over the other. Objective data about the arrangement of artificial teeth and its effect on oral functions and tissues is scant. Information is available regarding the location of the occlusal plane in relation to various anthropometric landmarks and reference points most commonly used by orthodontists. However, even this information is restricted to a young population under the age of thirty years.

Lundquist and Luther *(1970)* studied the location of occlusal plane in twenty Caucasian subjects having a full complement of dentition and ranging in age from twenty-one to thirty years with a mean age of twenty-six. These subjects were selected out of 3,000 patients to provide a sample with Class I occlusal relationship, with minimal restorations, and with minimal disharmony between centric relation and centric occlusion. The interrelationships between the plane of occlusion and four specified anatomic landmarks were observed. The occlusal plane in their study was considered to be a line joining the tips of the mandibular cuspids bilaterally to the tip of the distolingual cusp of the distal mandibular molar. When the plane was extended posteriorly, it terminated in 75 percent of the cases in the lower half, and in the remaining 25 percent, in the upper half of the retromolar pad. The use of the distobuccal cusp as the distal reference point resulted in the termination of the plane posteriorly in the upper half of the retromolar pad in most of the cases. The parotid papilla showed marked variation in its relative vertical and horizontal position to the buccal cusps of maxillary first and second molars. For the group, the average location of the papilla was 4.2 mm. superior to the tip of the buccal cusp of the adjacent maxillary molar and the total variation ranged from 0 to 10 mm.

A close correlation was also found by Lundquist and Luther *(1970)* between the commissure of the lips and the vertical location of the occlusal plane. In 75 percent of the cases, a wire extending across the occlusal embrassure between the mandibular cuspid and first premolars of both sides and through the commissure of the lips was found to be at the same vertical height as the occlusal plane. A close correlation was seen among the occlusal plane, buccinator grooves, and the commissures of the lips. It was, therefore, suggested by the authors that a vestibular impression technique be employed to determine the location of occlusal plane in edentulous patients. This technique involves injecting alginate impression material in buccal vestibules on both sides while the teeth are separated slightly and in centric closure. The impressions of buccal grooves are recorded by having a subject pucker his lips as though sucking or kissing. The confinement of material between the teeth and cheeks is focal to the vestibular technique. However, the location of the teeth or the bite rim is arbitrary in edentulous subjects. For this reason, the application of this technique has validity only if it can be established that irrespective of the arch form, the impression of the vestibular groove remains constant.

Ismail and Bowman *(1968)* compared the locations of the occlusal plane in cephalometric roentgenograms taken with natural teeth prior to their extractions and following the insertion of dentures in twenty subjects ranging in age from nineteen to sixty years with a mean age of 41.5. The anterior and posterior locations of the natural dentition occlusal plane differed significantly from those of the denture occlusal plane. A mean difference of 0.95 mm. with a range of −2 mm. to +2 mm. was found in the anterior region and a mean difference of 2.3 mm. with a range of 0 to 5 mm. was recorded for the posterior region. The authors recommended that the upper third of the retromolar pad be used as the posterior reference point for the orientation of the second mandibular molar.

Kapur and Soman *(1965)* studied twelve denture wearers to determine the effect of nine positions of food platforms on their chewing efficiency. The position of the food platform was varied in its buccolingual and superoinferior directions and in its anteroposterior inclination. Of these nine positions, the location of posterior teeth buccal to the crest of ridges was most detrimental to chewing efficiency. Significant reductions in masticatory performance resulted in subjects with good as well as poor ridges. The most effective location of the posterior teeth for masticatory performance was on the crest of mandibular ridge, at the height of lower cuspid, and parallel to the residual ridge.

## RESEARCH ON DIFFERENT OCCLUSAL FORMS

Many investigators have tried to compare the effectiveness of three types of occlusal forms and have dealt with the following four parameters: **a.** masticatory performance, **b.** denture base deformation and stress distribution, **c.** tissue response, and **d.** overall subjective preference of denture wearers.

## MASTICATORY PERFORMANCE

A number of studies involving actual tests and subjective responses of denture wearers have been conducted to determine masticatory effectiveness of the various occlusal forms. Three distinct approaches have been followed to establish the best form for comminuting food:

1. Comparison of two or more types of occlusal schemes in the same denture wearers
2. Comparison of different geometric markings in the same denture wearers
3. Comparison of chewing efficiency of a large sample of denture wearers with various occlusal schemes

**COMPARISONS OF DIFFERENT TYPES OF OCCLUSAL SCHEMES.** Thompson *(1937)* was one of the first to determine the extent to which dentures with different occlusal schemes can restore masticatory efficiency to the degree permitted by natural dentition. Chewing efficiency was measured in terms of the percentage of the test food passing through a standard size screen after a given portion of the sample had been chewed for a specified number of strokes. Several tests foods, including raw carrots, lettuce, cabbage, cold ham, celery, apples, and raw Irish potatoes were used. Four sets of occlusal forms, interchangeable in the same denture bases, were tested in one subject. These forms were: **a.** 30° anatomic, **b.** Trubyte 20° semianatomic, **c.** zero degree Hall inverted cusp, and **d.** Sear's channel teeth. A marked reduction in chewing efficiency was found only with Sear's channel teeth. The patient felt that he could not hold the food on these teeth for mastication. The other three types of teeth produced the same degree of comminution. The 30° anatomic teeth were further tested in four situations:

1. A patient with his old set of poor dentures; the maxillary denture rebased to merely provide comfort
2. The same set of dentures was made satisfactory by extending and relining the mandibular denture base and by establishing a three-point occlusal balance
3. Another patient had a satisfactory set of dentures with well balanced occlusion but with inclined planes flat and devoid of ridges
4. The same set in which supplemental ridges were carved into the occlusal surfaces

A considerable improvement in chewing efficiency was shown after the dentures were made satisfactory. Similarly, the introduction of supplemental ridges on the flat inclines of the teeth not only increased their chewing effectiveness, but the patient actually perceived this improvement.



It was a pioneering effort on the part of Thompson to lead the way in comparing various occlusal forms through actual measurements. His study, however, had two serious drawbacks. First, the three sets of variables investigated employed a different subject for each set. Results based on one subject were inconclusive. Second, chewing efficiency comparisons among the three sets of variables were made without taking into consideration the wide variations that exist among denture wearers in their chewing ability.

Similar attempts were made by Sobolick *(1938)*, Schultz *(1951)*, Payne *(1951, 1952)* and Trapozzano and Lazzari *(1952)*, each studying a variable on only one or two subjects. Sobolick *(1938)* measured the masticatory performance of five sets of duplicate dentures with different occlusal forms in his own mouth. The five test forms were: **a.** Trubyte 33°, **b.** Trubyte 20°, **c.** Modified French's, **d.** Tru Kusp, and **e.** Hall's inverted cusp. The findings of the chewing tests with four different foods revealed no clear evidence of the superiority of any one form. The subject ranked Hall's inverted cusp, Tru Kusp, and French's posteriors (in that order) to be more comfortable than the Trubyte 20° and Trubyte 33° teeth when the dentures were subjected to horizontal and vertical movements.

Schultz *(1951)* demonstrated reductions of 16 and 32 percent in the chewing efficiency of one subject when the lingual cusps of Trubyte 33° porcelain teeth set in balanced occlusion were reduced. Similarly, a 15 percent loss occurred after the maxillary buccal cusps were modified to a slight minus cusp form. In another series of tests with interchangeable acrylic resin and porcelain posterior teeth, a 33 percent loss in chewing performance was noted with acrylic resin teeth. The patient, however, was unaware of this loss and preferred the acrylic resin teeth because of their cushioning effect on tissue. Efficiency was restored to that of the porcelain teeth by constructing gold onlays over acrylic resin teeth without affecting their cushioning property.

Payne *(1951)* constructed two sets of dentures on duplicate casts for one subject. One set had Trubyte 33° teeth and the other nonanatomic teeth. After an acquaintance period, the patient recorded (for two weeks) her experiences with the two sets of dentures, which she used on alternate days. Both the subjective evaluation of the patient and the investigator's observation of the particle size of the chewed test foods revealed a superiority of anatomic teeth over nonanatomic teeth.

In a subsequent study, Payne *(1952)* drew somewhat similar comparisons between the Trubyte 33° anatomic teeth and a different nonanatomic pattern on duplicate dentures in five subjects. The four nonanatomic patterns tested were: **a.** Tru Kusp, **b.** French's, **c.** La Due and Saffir, and **d.** Hardy's steel inserts. French's posteriors were the only teeth tested in two subjects. Chewing efficiency was evaluated by a careful visual examination of the consistency, particle size, and uniformity of the food. Four subjects considered anatomic teeth to be better for chewing while the fifth preferred the steel inserts. All subjects favored dentures with nonanatomic teeth. Chewing tests showed better performance with anatomic teeth at the halfway mark, but at the swallowing threshold, nonanatomic teeth were shown to be better for two of the three test foods.

Trapozzano and Lazzari *(1952)* compared the performance of Trubyte 20°, Hall's inverted cusp, and De Van's nonanatomic posterior teeth in two subjects. Special metal cast bases were constructed to permit the interchangeability and testing of these three occlusal forms. Raw carrots and peanuts were employed as test foods. The amount of test food and the number of strokes for each mouthful were specified, although the size of the bolus and the number of mouthsful were left to the discretion of subjects. Masticatory efficiency was determined by weighing the particles passing through a 100 mesh screen. The particle size distribution of chewed carrots was compared visually. In both subjects, 20° teeth showed markedly superior chewing performance with peanuts, caused less tissue irritation, and received an overall patient preference when compared to the nonanatomic teeth. In one subject, performance with carrots was considered to be superior with Hall's inverted cusp teeth than with the other two types of posterior teeth.

A similar approach was used in another study by Trapozzano *(1959)* where he compared Trubyte 20° teeth with Hall's posterior teeth in eight denture wearers. Patients were encouraged to freely express their opinions. It was not uncommon to find subjective evaluations contradicting objective findings. For example, despite the presence of tissue ulceration, some subjects responded negatively to the question, "Do dentures cause you any pain?" The 20° teeth were more effective in comminuting test foods than were Hall's posterior teeth. Four patients voiced strong preference for the 20° teeth, one for the 20° teeth with some qualification, one preferred the Hall's posterior teeth, and two had no preference.

Bascom *(1962)* also tested interchangeable occlusal schemes on metal bases in six subjects. Both Trubyte 33° and 20° teeth were compared with Myerson-Sears posteriors in three subjects with Myerson-Sears and with flat acrylic resin teeth in two subjects, and with Hardy's steel inserts in one subject. Standard chewing tests revealed no clear-cut superiority with any one occlusal form. The subject's preferences were divided. Bascom also constructed duplicate dentures to compare the 33° teeth with Hardy's insert teeth in one subject, with French's posterior teeth in a second subject, and with 30° Pilkington-Turner teeth in a third subject. Again, no appreciable differences were noted in chewing efficiency.

Kapur (unpublished data) constructed (on duplicate casts) three sets of dentures to compare Pilkington-Turner 30°, Trubyte 20°, and flat acrylic resin block teeth with selected geometric patterns in twenty subjects. Standardized chewing tests showed no significant differences among the mean masticatory performances obtained with the three occlusal schemes. Mean chewing efficiency, respectively, for the 30°, 20°, and zero degree teeth were 68, 67, and 69 percent for peanuts, and 64, 60, and 62 percent for carrots.



**COMPARISON OF VARIOUS TYPES OF GEOMETRIC MARKINGS ON NONANATOMIC OCCLUSAL SURFACES.** The influence of different occlusal markings on masticatory performance has been studied both in persons with natural dentition and in denture wearers.

Sauser and Yurkstas *(1957)* placed (on posterior teeth) acrylic resin splints in five subjects with natural dentitions. The splints were modified to produce eleven combinations of geometric designs. Chewing tests with peanuts, raw carrots, and ham showed superior performance when the cutting edges (grooves) were present on both maxillary and mandibular occlusal overlays than when one or both lacked markings. The highest performance was seen with a longitudinal groove running mesiodistally on the maxillary occlusal surface against several types of markings on the mandibular occlusal surface.

In another study, Yurkstas *(1963)* tested twenty denture wearers for the chewing effectiveness of four different gometric patterns carved on the occlusal surfaces of block acrylic resin teeth. He compared their effectiveness with four similar configurations of raised metal inserts. Occlusal surfaces with markings were more effective in comminuting food than were the surfaces without markings. No significant differences were noted among the four grooved patterns or between the grooved and metal insert designs. However, improvement occurred when tests were made after three months experience with metal inserts and after one years experience with a given grooved pattern.

Kapur and Soman *(1965)* evaluated the masticatory effectiveness of fifteen different geometric occlusal markings in sixteen denture wearers. The presence of occlusal markings significantly improved the masticatory ability. The most effective combination of markings was a mesiodistal longitudinal groove on the mandibular occlusal surface opposed by either a transverse or oblique marking on the maxillary occlusal surface. However, no correlation was found between performance and number of cutting edges or grooves. It was hypothesized that the markings provide resistance against buccolingual displacement of food rather than acting as cutting edges during mastication.

Kapur, Soman, and Shapiro *(1965)* also studied the influence on masticatory efficiency of the food platform area, the buccal and lingual tooth surface contours, and metal inserts in sixteen denture wearers. Again, it was shown that the presence of occlusal markings, whether grooves or inserts, improved chewing efficiency. The area of the occlusal platform (equivalent to two, three, or four posterior teeth) had no effect on performance.

**CHEWING EFFICIENCY STUDIES OF LARGE SAMPLES.** Manly and Vinton *(1951)* made a comprehensive study of 100 denture wearers to identify and study the factors contributing to masticatory function. The factors included denture age, denture experience, patient age, maximum biting force, tough tissue tolerance, and various denture properties. In fifty-nine denture wearers with anatomic teeth, and twenty-nine with nonanatomic teeth, the differences between the effectiveness of these two types was not enough to account for the great spread between superior and poor masticatory performance of the subjects. There was no correlation between masticatory performance and any of the other denture properties, especially with dentures rated "clinically adequate."

Kapur and Soman *(1964)* tested the masticatory function of 140 subjects who were divided into three groups. The dentures of the first group were made with nonanatomic teeth by undergraduate students. The dentures of the second group were made with nonanatomic teeth by graduate students. The third group of denture wearers was randomly chosen and their dentures represented a whole spectrum of materials, techniques, and occlusal schemes. Insignificant differences among the masticatory performances of these three groups indicated that denture factors cannot explain the vast differences in the chewing ability of denture wearers.

## DENTURE BASE DEFORMATION AND STRESS DISTRIBUTION

A number of studies have been carried out in denture wearers to determine the masticatory pressures exerted on the denture bearing tissues by different types of occlusal forms. Four approaches were taken: **a.** measurement of denture base deformation, **b.** measurement of jaw and denture movement, **c.** electromyographic quantitation of muscle force, and **d.** frequency and location of occlusal contact.

**DENTURE BASE DEFORMATION.** Frechette *(1955)*, Kydd *(1956, 1960)*, Swoope and Kydd *(1966)*, and Stromberg *(1955)* placed strain gages on denture bases to measure changes in gage resistance while subjects performed chewing tests. By calibrating the gages with known forces, resistance changes were expressed either in terms of pressure or base deformation.

Frechette *(1955)* employed this method in one subject to compare the masticatory pressures produced by zero degree geometric, 20° diatoric, 30° Pilkington-Turner, and Hardy's metal inserts. Special metal base castings with interchangeable dentition overlays were constructed. After the denture wearer had an opportunity to become familiar with each dentition, pressures in six areas of the maxillary denture were measured while the subject chewed standardized portions of peanuts, carrots, and ham. The six test areas were the ridge crests, and the buccal and palatal surfaces of the base subjacent to the mesial of the first maxillary molars of both sides. The best chewing was done by the 30° teeth and the poorest by the metal inserts. With 30° teeth, there was less pressure on the crest of the ridge, but more pressure than with the other forms in three of the four lateral areas. The 20° teeth showed the maximum pressure on one crest and in-between pressure on the other crest. The lateral areas registered in-between pressure in three areas and the least pressure in the fourth area. The zero degree teeth exerted the maximum pressure on one crest and the least pressure on the other crest, and in two lateral areas. The same amount of pressure as the 20° teeth was observed in the third area, while the least pressure was recorded in the fourth lateral area. Compared to other forms, the Hardy's steel inserts produced the greatest pressure on one crest and the least on the other, but produced the least amount of pressure in three of the four lateral areas.

Kydd *(1956)* compared the horizontal mandibular denture base deformation associated with zero degree, 20°, and 30° teeth in one denture wearer during mastication. The 30° teeth caused the greatest base extension (0.51 mm.). This deformation was 10 percent greater than that caused by the 20° teeth and 50 percent more than by the zero degree teeth.

Three occlusal schemes were studied in another group of five subjects by Kydd *(1960)*. He found no significant differences among the masticatory performances of the three occlusal patterns. However, both 33°, and 20° teeth caused significantly greater denture base deformation than that caused by the zero degree teeth. The 33° teeth caused 100 percent, and the 20° teeth 68 percent greater compression of the denture base than that caused by the zero degree teeth. The average extension was 33 percent greater with both types of cusp teeth than with the zero degree teeth.

Similar findings were obtained in another study by Swoope and Kydd *(1966)* in denture wearers. During chewing, both types of zero degree teeth (with wide and narrow buccolingual surfaces) showed significantly less compression and extension deformations of denture base than those caused by the 30° teeth. However, the three types of occlusal forms caused approximately the same amount of deformation during swallowing.

Stromberg *(1955)* used a different approach to measure forces placed on denture bases during mastication. A small area of the tissue surface of acrylic resin denture base was permitted to move freely, like a plunger within the base. The plunger was cemented to a thin beam carrying a strain gage. Plunger movement during mastication caused beam deflection which resulted in changes in gage resistance. In order to measure lateral pressures, a test area was located in the right and left buccal flanges adjacent to maxillary first molars. Zero degree and 33° teeth were tested on duplicate dentures in two subjects. Bilateral pressure measurements showed that the pressures exerted on the chewing side with 33° teeth were approximately twice as much as with zero degree in one case and about the same for both types of teeth in the other case. The nonchewing side showed the same or slightly higher pressures with the zero degree teeth.

Sharry, Askew, and Hoyer *(1960)* studied the distribution and amount of strain induced by the occlusal loading of mandibular dentures (on edentulous skulls) with anatomic and nonanatomic teeth. A strain-sensitive lacquer was applied on the skull for this purpose. Greater bone deformation was evident beneath anatomic tooth forms than beneath nonanatomic tooth forms. Bone deformation was seen in areas remote from the site of loading and concentrated around foraminae.

**MEASUREMENT OF JAW AND DENTURE MOVEMENT.** Cinephotography was used by Woelfel, Hickey, and Allison *(1962)* in their study to determine the influence of occlusal form on jaw and denture movement. The three types of occlusal schemes tested were: **a.** 33° teeth with bilateral balance, **b.** 20° teeth with bicuspids and the first molars positioned with a reverse buccolingual curve, and **c.** zero degree teeth on a flat plane with the second molars inclined to serve as ramps. Complete dentures with interchangeable posterior forms were constructed and tested in six subjects. The shape of the masticatory cycles was generally not influenced by the posterior tooth form. Neither the size nor the shape of masticatory cycles was changed as the comminution of food took place. The closures were slightly anterior to the opening movement with both the nonanatomic and semianatomic occlusal forms. The closure was posterior to the opening cycle with the anatomic form. However, the closures with all three forms were in close proximity to the posterior portion of the envelope of motion. The movement of maxillary dentures was minimal in five cases and fell within a radius of 1 mm. with all three types of teeth. In the sixth subject, with an unfavorable mandibular ridge, the movement of the maxillary denture ranged between 5 to 7 mm. with the 20° reverse curve occlusal scheme and less than 2 mm. with the nonanatomic and anatomic forms.

Smith, D. E., *et al.* *(1963)* measured the movement of maxillary and mandibular dentures in relation to the underlying bone in seven denture wearers while they chewed test foods. Two vitallium metallic pins were embedded in the mandible, one at the midline and the other in the area of the first molar. Two lead markers were placed directly superior to the bone-embedded pins. Three radiopaque markers, one in the midline and the other two corresponding to each first molars, were placed in the maxillary dentures. Lateral and anteroposterior radiographs were taken as the subject chewed raw carrots while his head was fixed in the cephalostat. The maxillary and mandibular dentures both showed considerable movement. The movement of the maxillary denture was mainly horizontal and the mandibular denture mainly vertical. However, no statistical difference was found in the amount of movement between the maxillary and mandibular denture. As much as 2.5 mm. of movement was exhibited by well-adapted dentures on residual ridges. Thus, the authors questioned the desirability of precise intercuspation in complete dentures.



**ELECTROMYOGRAPHIC QUANTITATION OF MUSCLE FORCE.** Hickey, *et al.* *(1963)* reported their findings on the analysis of the electromyographic recordings of the closing masticatory muscles of nine denture wearers with the same three types of occlusal schemes. Peanuts served as test food in six subjects, raw carrots in five subjects, and unvulcanized rubber in all nine subjects. With peanuts and carrots, the combined average muscle activity of closing muscles was markedly higher (20.5 percent with peanuts and 34.6 percent with carrots) with 20° teeth arranged with reverse buccolingual curve and slightly higher (5.1 percent with peanuts and 9.4 percent with carrots) with zero degree teeth than those with anatomic teeth. The combined muscle activity recorded for chewing unvulcanized rubber was almost identical for the nonanatomic and semianatomic teeth and came to 12.2 percent higher than that employed with the anatomic teeth.

**FREQUENCY AND LOCATION OF OCCLUSAL CONTACT.** Contact of the opposing occlusal surfaces of teeth during function has been studied with great interest both in subjects with natural dentition and with complete dentures. In earlier studies, tooth contact was recorded as an electrical potential difference between two opposing metallic surfaces.

Jankelson, Hoffman, and Hendron *(1953)* found no evidence of occlusal contact during mastication in persons with natural teeth or in denture wearers. Occlusal contact was recorded only during deglutition.

Yurkstas and Emerson *(1954)* found evidence of frequent contact of the balancing and working occlusal surfaces of dentures in all twelve subjects. Occlusal contact occurred with every chewing stroke on the balancing side. The frequency of contact on the working side was slightly less and was increased by the amount of pressure exerted during chewing.

Kaires *(1957)* studied the occurrence of functional occlusal contacts in sixteen denture wearers. Several types of occlusal schemes were used in their dentures. Electrical recordings of occlusal contacts during chewing of several test foods revealed variations among subjects and among trials. The frequency of contacts was related to the test food rather than to the type of occlusal form. The use of denture adhesive reduced the frequency of contacts in patients whose dentures lacked stability and retention.

In another study, Kaires *(1959)* tested anatomic and nonanatomic occlusal schemes in one subject. The areas of contacts during chewing did not coincide with the contact areas established on the articulator. No difference was noted between the two occlusal schemes.

Miniaturization in electronics has made it possible to place transmitters in individual teeth so that signals generated by the contacting metallic surfaces could be transmitted and continuously recorded. Several sophisticated devices have been designed and placed in both artificial and natural dentitions *(Brewer and Hudson, 1961; Brewer, 1963; Graf and Zander, 1963; Scott and Ash, 1966; Glickman, Pamjier, and Roeber, 1968).*

Brewer and Hudson *(1961)* employed this method in two denture wearers and found that the number of contacts varied during chewing and was influenced by the type of test food. The frequency and character of contacts were also affected by the type of occlusal form and by the prematurity in occlusal balance. Occlusal prematurity on the balancing side increased the number of contacts on that side and reduced the number on the working side.

Brewer *(1963)* counted the number of occlusal contacts which occurred during masticatory and nonmasticatory periods in eight subjects with complete dentures over a period of several months. Occlusal contacts during chewing were evident in all subjects. Six of the eight subjects showed contact on almost every chewing stroke. The frequency was dependent upon the type of test food and occlusal form. A proper occlusal balance in cusp teeth provided a smooth pattern of contacts which occurred both at the cusp tip as well as in centric occlusion. This evidence of the use of lateral chewing strokes was noted in all subjects. Wide variations were noted in the number and duration of nonmasticatory contacts. During waking periods, the number of contacts varied from 150 per hour to 1500 per hour. During sleep, the total contact period ranged from 3 to 15 minutes for some patients to 1-1/2 to 2-1/2 hours for others.

Telemetric procedures have since been applied to attempt to answer the important question, "Do functional contacts occur in centric relation or in other positions?"

## TISSUE RESPONSE

Trauma from occlusal prematurity is generally considered to be one of the prime reasons for tissue soreness and resorption of ridges. The proponents of the various types of occlusal forms argue that their form is the least detrimental. Tallgren *(1969, 1972)*, and Atwood *(1957)* have measured changes in facial and residual ridge heights. However, there has



been no major longitudinal epidemiological study to determine the various systemic and denture factors on ridge resorption in denture wearers.

Woelfel and Winter *(1970)* reported on a study in which three groups of fifteen subjects were followed over five to eight years for changes in facial height and for areas of maximum residual ridge bone loss. The subjects in the first group received dentures with anatomic teeth; the second, semianatomic teeth; and the third, nonanatomic teeth. The greatest bone loss and closure of occlusal vertical height was found in the group with nonanatomic teeth; the least with anatomic teeth. Although these differences were found to be statistically insignificant, the authors felt that 1 mm. difference of alveolar bone resorption between the nonanatomic and anatomic should be considered clinically significant.

## SUBJECTIVE EVALUATION OF DENTURE WEARERS

Brewer, Reibel, and Nassif *(1967)* constructed duplicate dentures for twenty-five male patients, one with 33° anatomic posterior teeth and the other with zero degree teeth. Subjective appraisals of their dentures by subjects after six weeks to twenty-three months of use revealed that eleven preferred dentures with zero degree teeth, two with anatomic teeth, ten had no preference, while the remaining two dropped out of the study due to neuropsychiatric reasons. It was also pointed out by the investigators that only two subjects realized on their own that they had used two sets of dentures. Even in these two cases, the subjects perceived difference in a characteristic other than the occlusal form.

Woelfel, Hickey, and Allison *(1962)* also found among their six subjects that preferences were equally divided for the anatomic, semianatomic, and nonanatomic types of teeth.

In another study, Brewer *(1970)* compared the response of twelve subjects to dentures made by seven dentists who used different occlusal forms. The seven occlusal forms tested were: **a.** Hardy's steel inserts, **b.** zero degree acrylic resin, **c.** zero degree porcelain, **d.** zero degree maxillary acrylic resin and mandibular porcelain, **e.** 20° porcelain, **f.** 30° porcelain, and **g.** 33° porcelain. Although dentures with Hardy's steel inserts were considered to be the most efficient by all the patients, none chose this set for his future use. No occlusal form was found to be outstanding for comfort, esthetics, and chewing.

## DISCUSSION

The ideal occlusal form and tooth arrangement in dentures should provide comfort, esthetics, mastication, phonetics, and preservation of denture-bearing tissues. Of these five qualities, esthetics and phonetics appear to be the least affected by occlusal forms of posterior teeth. Their measurement is subjective and difficult. On the other hand, masticatory effectiveness, tissue response, and patient comfort are parameters which can be defined and measured with a certain degree of accuracy. Therefore, an occlusal form could be considered optimum for chewing if it achieves maximum communition with comfort and minimum effort without exerting unfavorable pressures on the supporting tissues. Thus, a measure of masticatory performance should include both the degree of pulverization as well as the amount and direction of forces associated with it.

Most studies on mastication to date have been devoted either to the degree of communition achieved by vaious forms or to the occlusal forces or muscle effort associated with mastication. Despite many excellent technical efforts made in designing dentures that could be tested under controlled conditions, many of these studies have serious flaws in research methodology. Very little attention has been given to defining parameters or to developing methods to measure them reliably. For example, where patient evaluations were used to compare the efficiency of different forms, there was no systematic, pretested and validated questionnaire. Most studies ignored standard statistical approaches which call for the forming of a hypothesis and then testing it. Frequently, only one or two subjects were involved in the investigations. When more subjects were included, additional variables were often introduced so that results were still drawn on one or two subjects.

From all the studies cited in this review, certain conclusions emerge:

1. The average chewing ability of a denture wearer is extremely limited and is about one-sixth of that possessed by an average person with natural dentition.
2. There were wide variations in chewing ability among denture wearers. Very few showed chewing ability comparable to natural dentition.
3. Various denture factors, including retention, stabiliy, tooth forms, and arrangemenents, fail to explain the wide differences in chewing ability among denture wearers *(Kapur, Soman, and Shapiro, 1965; Kapur and Soman, 1965; Kapur, 1967; Langer, Michman, and Seifert, 1961)*.
4. Similarly, other variables among subjects, (i.e. tissue tolerance, ability to apply force, age, sex, denture experience, and denture bearing tissues and ridges) were found to show limited or no influence upon chewing ability.

The wide variations in chewing ability among denture wearers can be explained at present only on the basis of impairments of sensory processes involved in food manipulation during function. It has been pointed out that mastication is the result of a highly complex neuromuscular and digestive activity by Kawamura *(1964)*. The communition of food occurs



primarily between the occlusal surfaces of teeth, which are brought into action by the movements of the mandible. Proprioceptors in the muscles, temporomandibular joints, and the periodontal membrane of teeth are helped by various sensory cues from the food to direct the movements of the mandible.

The effectiveness of the manipulating system regulates grinding by continually carrying particles to the food platform for pulverization. This demands appropriate selection, transportation, and confinement of larger particles to the occlusal surfaces of teeth. Thus, if the ability to discriminate is lessened and if not enough coarse particles are brought to the food platform, even the best chewing mechanism cannot be expected to grind food well.

The mouth possesses the complex ability of stereognosis to perceive texture, form, size, and consistency of three-dimensional objects and to help determine which objects should be swallowed or chewed. The two structures directly involved in manipulating food during mastication are the tongue and cheeks. The tongue actively dominates in this function, for which it is well suited by nature of its two-point discrimination sensitivity and its highly developed tactile localization. Efficiency in food manipulation can be lost through impairment of the sensory feedback mechanism (afferent system), integrating system, or of the efferent system.

It has been shown by Manly and Braley *(1950)* that mastication in persons with natural dentition is selective in the sense that coarse particles of food are ground more rapidly than are fine particles as chewing progresses. On the contrary, a random and nonpreferential pattern of chewing was evident in denture wearers in studies by Kapur, Soman, and Yurkstas *(1964)*. It was hypothesized that impairments in the sensory feedback mechanism may be chiefly responsible for the nonpreferential chewing pattern in denture wearers. Support for this theory was provided in another study by Fischer and Kapur *(1966)*, where blunted oral sensations, produced by local infiltration anesthesia in subjects with natural dentition, caused a similar nonpreferential chewing pattern. Studies of textural discrimination in denture wearers have shown that this ability is impaired *(Kapur and Collister, 1970)*. If this hypothesis is true, one can say that no substantial improvement in the chewing ability of denture wearers can be made through improved designs of occlusal form. The solution would lie in radical changes in denture designs, materials, and in physiotherapeutic approaches.

Because studies of denture base deformation and stress distribution have been limited to very few subjects, no significant conclusions can be made. However, deformation of dentures, along with its tilting and tipping, was evident in all the studies. Such deformation was somewhat greater with anatomic than with nonanatomic teeth. However, there is no way to ascertain whether the magnitude and direction of these stresses are critical to bone resorption often observed in denture wearers. The problem is also complicated because the edentulous condition is most prevalent in older persons who may have other systemic problems. Diagnostic tools are lacking to predict the response of tissues. Modern nuclear medicine has provided new methods now being tried to study the pathophysiology of bone.

## CONCLUSION

It is apparent from this review that there is no outstanding occlusal form or arrangement of teeth among those presently available. Occlusal form, tooth arrangement, and for that matter, the "clinical excellence" of dentures appear not to be the key determining factors in denture efficiency. In other words, the maximum function attainable with the present types of dentures can be achieved by most of the prevalent forms and technics.

Present forms and denture designs are based primarily on certain anatomical and mechanical considerations, which are thought to be advantageous for retention, stability, and functions. They are not established on truly physiological concepts because knowledge of oral functions and bone pathophysiology for this purpose is nonexistent. As a result, little or no advancement has been made in this area over the past thirty years. For progress in complete denture prosthodontics to occur, it will be necessary to investigate in depth the neurophysiological processes associated with oral functions and the biophysical principles of bone metabolism. Further, interaction of these activities should be studied in relation to denture designs and materials.

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# SECTION REPORT

## INTRODUCTION

The following premises were agreed upon as a basis for discussion of occlusal patterns and tooth arrangements:

1. The artificial denture is an inert, relatively rigid prosthesis which is subject to physical laws. Furthermore, the prosthesis is placed in a changeable environment which is prone to both immediate and progressive post-insertion changes.
2. The nature of occlusal force distribution, and the area over which it is distributed, differs in natural and artificial dentitions.
3. Mandibular closure takes place in an essentially upward direction, and generates multidirectional occlusal forces. It is probably desirable to design occlusal schemes which will enable generated forces to be as near vertical as possible, as well as being distributed over the maximum denture bearing tissues.
4. Artificial dentures should be designed to fulfill esthetic requirements and fabricated to enable a patient to perform oral functional movements with minimal tissue damage. Consideration must also be given to prevention of trauma by para-functional occlusal contacts.

*All findings of this Section must be considered in the light of their agreement that insufficient documentation exists in all areas considered.*

## OCCLUSAL PATTERNS

Anatomic and semianatomic teeth were grouped together for comparison since most investigators have failed to show any real difference between these types of teeth.

Interactions between denture factors and patient factors are known to exist, but the nature of these interactions with occlusal patterns and tooth arrangements are ill-defined and not clearly understood. Much research is needed to evaluate these factors on successful complete denture treatment. The denture factors selected for study were stability, retention, and occlusal harmony. The patient factors were tissue tolerance, ability to apply force, and the physical and emotional health of the patient.



## DENTURE FACTORS

**STABILITY.** It was found that anatomic occlusal patterns cause a greater denture base deformation than nonanatomic teeth during function *(Frechette, 1955; Stromberg, 1955; Kydd, 1956, 1960; Sharry, Askew, and Hoyer, 1960; and Swoope and Kydd, 1966).* Since transverse denture base deformation is primarily a function of lateral forces, it may be deduced that greater lateral forces were recorded with anatomic than with nonanatomic teeth. Thus demands on denture base stability may be increased with the use of anatomic patterns. However, these studies were somewhat limited in scope and it was felt that further investigation is indicated.

**RETENTION.** Studies have shown extensive denture movements during function with both types of occlusal patterns. Further research is needed.

**FUNCTIONAL OCCLUSAL HARMONY.** The influence of posterior denture tooth patterns on the maintenance of occlusal harmony was examined under two categories. *Normal function*—It was noted that extensive movements of denture bases occur during mastication and swallowing *(Sheppard, I. M. and Sheppard, S. M., 1971 and Smith, D. E., et al., 1963).* This degree of denture movement probably precludes harmonious occlusal relationship during normal function. *Long term function*—In the context of long term effects of complete dentures on the oral tissues, the resultant changes in occlusal harmony were noted. Allowance must be made in the occlusal pattern to accommodate for this continuous change.

## PATIENT FACTORS

**TISSUE TOLERANCE AND ABILITY TO APPLY FORCE.** It was apparent that definitive knowledge is lacking in this area and the recommendation for further investigation is made.

**MASTICATORY EFFICIENCY.** It was accepted that the influence of occlusal patterns on masticatory efficiency has been documented. The character of the occlusal surface, whether it be anatomic or nonanatomic, does not affect the masticatory performance in the complete denture wearer.

**FACTORS PERTINENT TO THE SELECTION OF THE OCCLUSAL FORM.** The following individual factors should be considered in the selection of the posterior occlusal tooth forms. *Esthetic requirements*—Whenever esthetic requirements are paramount, the use of the anatomic tooth form is considered. *Age*—The prosthodontic requirement in the young individual with minimal interarch distance may necessitate the use of anatomic tooth forms. In the geriatric patient, the use of nonanatomic teeth is preferred because of increased denture problems. *Abnormal ridge relations*—It has been documented that persons with Class II jaw relationships demonstrated a tendency for an increased protrusive functional range (*Posselt, 1968; and Ingervall, 1964*). Nonanatomic teeth may be employed with greater ease to accommodate this functional need of the patient. *Class III jaw relationship*—Nonatomic teeth are more readily arranged in cross-bite relationship which is often required by these patients. *Excessive interarch distance*—This is considered an indication for using nonanatomic teeth because of the unfavorable leverage factors created by the distance of the occlusal plane from the residual ridges. *Denture experience*—Studies have shown that change from one occlusal form to another did not affect patient acceptance of their dentures *Brewer, 1970*). *Opposing occlusal scheme*—The occlusal pattern for a complete denture opposing a natural posterior dentition or a partial denture restoration can be dictated by the occlusal form of the opposing dentition. *Emotional health*—Several investigators consider emotional stress to be a factor in parafunctional activities. Stresses from the ensuing tooth contacts will be more likely to be transmitted in a vertical direction with nonanatomic teeth than with anatomic teeth.

## TOOTH ARRANGEMENT

**ANTERIOR TEETH.** The primary objective in arrangement of the anterior teeth is to secure satisfactory esthetics and phonetics. Development of occlusion may require modification of anterior tooth position from the most desirable esthetic and phonetic position. The following are principal guidelines influencing anterior tooth arrangement. *The incisive papilla*— The central incisors should be placed anterior to the incisive papilla. *Reconstructed ridge*—The projected roots of the denture teeth should fall within the ridge outline when it is visually reconstructed by an imaginary restoration of lost ridge contour. *Pre-extraction records*—Pre-extraction records are one of the most reliable methods and should be obtained whenever possible. Some modifications to natural tooth position are often indicated. *Phonetics*—The use of phonetic sounds can be helpful to determine the relationship of the maxillary anterior teeth to the lower lip and of the maxillary teeth to the mandibular teeth. Clinical experience has confirmed the use of this method, but research documentation is lacking. It has been observed that the adaptive capacity of individuals is considerable and liberties relative to phonetic guides may often be taken with but little permanent influence on speech. *Previous denture experience*—Radical departure in tooth position from previous denture experience may result in functional problems as well as problems with patient acceptance. *Familial similarities*—Familial similarities often exist between parent and child and should be used as a clinical guide whenever possible.



**EFFECTS OF ANTERIOR TOOTH POSITION ON DENTURE RETENTION AND STABILITY.** Esthetics is a major consideration in the placement of the maxillary anterior teeth, even though it may slightly diminish the retention and stability. The mandibular anterior teeth are not as critical to the maintenance of facial contour, so they should be positioned to minimize dislodging forces. The most desirable tooth position (esthetically) may have to be altered to provide occlusal harmony, depending upon the requirements for a balanced or unbalanced occlusion.

**POSTERIOR TEETH.** The position of the posterior teeth on complete dentures can affect qualities such as stability, retention, occlusal harmony, masticatory effectiveness, force tolerance, esthetics, and phonetics (Table 1). There are two principal approaches to the problem. The first is to achieve the maximum stability of the dentures; the second stresses the duplication of the previously existing dental structures. Positioning of the posterior teeth in the exact location of the previously existing natural teeth results in very desirable esthetic and phonetic qualities. However, the other stated qualities are often less than optimum. Therefore, certain modifications of the natural tooth position may be indicated.

TABLE I
FACTORS EFFECTED BY POSTERIOR TOOTH POSITION

| | | Stability | Retention | Masticatory Efficiency | Force Tolerance | Phonetics | Esthetics |
|---|---|---|---|---|---|---|---|
| Based on Mechanical Principles | Maxillary | ⊕ | ⊕ | □ | ⊕ | ⊖ | ⊖ |
| | Mandibular | ⊕ | ⊕ | □ | ⊕ | ⊖ | ⊖ |
| Based on Natural Position | Maxillary | ⊖ | ⊖ | □ | ⊖ | ⊕ | ⊕ |
| | Mandibular | ⊖ | ⊖ | □ | ⊖ | ⊕ | ⊕ |

⊕ = favorable effect, not documented
⊖ = unfavorable effect, not documented
□ = some documentation, but more research needed.

**GUIDES FOR DETERMINATION OF THE OCCLUSAL PLANE FOR POSTERIOR TEETH.** External landmarks such as the ala-tragus line should only be used as a starting point in determining the inclination of the posterior occlusal plane. Several valuable guidelines have been shown to be related to the level and inclination of the posterior occlusal plane. In the first premolar region, the plane should be at or below the level of the commissures of the lips at rest. The level of the retromolar pad is a reliable landmark in the posterior region and the occlusal plane should not terminate above the level of the pad. In the majority of patients it should intersect near the center of the pad. However, it is conceded that the long term stability of the pad's location is not documented. Modifications in the level and inclination of the plane can be made to improve stress distribution.

## OCCLUSAL CONCEPTS

The Section members believe that the arrangement of individual teeth in selected occlusal concepts can result in inclinations which were not designed into the teeth. For example, the use of nonanatomic teeth does not necessarily ensure a monoplane tooth arrangement. The incorporation of anteroposterior occlusal plane curvatures may result in the delivery of torquing forces to the denture.

## SUMMARY

At present, the choice of a posterior tooth form or arrangement for complete dentures is an empirical procedure. Little or no supporting research is available to the profession relative to the overall effect on esthetics, function, and the long term maintenance of the supporting tissues. All of the occlusal forms may be arranged with or without bilateral balance. A great many claims and counterclaims appear in the literature extolling the merits of a given concept or pointing out the deficiencies of another. Scores of clinically competent and intellectually honest professionals document clinical experiences in a very subjective manner. Since their experiences differ and their conclusions conflict, the practitioner is left to make his own choice. The available research fails to identify a superior tooth form or arrangement, therefore it appears logical to use the least complicated approach that fulfills the *requirements of the patient.*

Respectfully submitted,

Charles M. Moore, *Chairman*
Dale E. Smith, *Secretary*
Krishan K. Kapur, *Reviewer*

Marvin E. Baxla
Charles L. Bolender
A. Andersen Cavalcanti



Earl E. Feldmann
Ernest L. Miller
Mahmoud F. Nasr
Joseph J. Visceglia

A. Albert Yurkstas
George A. Zarb
Gerald Graser, *Section Assistant*

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Swoope, C. C., and Kydd, W. L. The effect of cusp form and occlusal surface area on denture base deformation. *J. Prosth. Dent.*, *16*:34–43, Jan.–Feb. 1966.

## DISCUSSION OF REPORT

Following the reading of the Section report by chairman Moore, a motion for its acceptance was made by Baxla and seconded by Bolender. The motion was defeated by the members of the General Assembly. Koper made the motion to open the report to discussion which was seconded by Larkin and approved. A lengthy discussion of the report ensued before Aull made the motion to table the vote on acceptance of the Section report and asked that the members of the Occlusal Patterns and Tooth Arrangements Section adjourn and reconsider their report, then return to the General Assembly later in the day for a second reading. The motion was seconded by Lang and approved by the General Assembly.

Moore returned to the meeting and read the revised report published herein. The chairman of the General Assembly requested a motion for acceptance of the report. Zander responded, "I would like to move that we accept the first page [introduction] and the summary statement of this document, both of which are excellent, for the following reasons. We all received a letter that stated the primary purpose of the Workshop is a scientific appraisal of the current knowledge of complete denture occlusion, with every effort being made to arrive at conclusions based on factual scientific evidence, and not unsupported empirical theories. It states in the introduction of the Section report that there was insufficient documentation. The summary again states everything very clearly. Between the introduction and summary are items which are not documented, but empirical statements that make recommendations, and I don't think that this was the purpose of this Workshop. Therefore, I move again to accept page number one [introduction] and the summary statement of this report." The motion was seconded by Celenza.

Kapur commented that Dr. Zander accepted such statements in the previous Section's report. For example, "It is the opinion and clinical experience of many that pantographic registrations can be reproduced for edentulous subjects. This we accept even though it has yet to be established in the literature." "So," continued Kapur, "I am wondering why there is a dual approach with acceptance of these reports. I think we have accepted the reports which have not taken any position, and if this is what we are interested in, I think we should have adjourned after the review papers had been submitted to the Organizational Committee, because everything has been mentioned in the review." He added



that "the purpose of this gathering is to try to come up with some position which, in the opinion of an intellectual body like this, would provide guidelines so that we could go back and be able to apply *them* rather than principles which were established by subjective judgments with no validation."

Regarding the lack of documentation mentioned by Zander, Kapur cited the references given for the topic *stability* under denture factors. Zander responded, "I moved to accept the introduction and the summary statement. I think they are excellent and truly state our present state of knowledge on this subject matter. . . . there is nothing wrong with accepting this report; it is a two page report. The summary statement really states the state of the art and the first page [introduction] helps us a great deal. In between these sections there are too many things that most of us will not agree with—that's why I made this motion."

Woelfel suggested that the occlusal patterns and denture factors sections also be accepted. The amendment was not acceptable to Zander.

Celenza objected to the implication in the report that nonanatomical teeth transmit fewer forces than anatomical teeth.

Woelfel felt that some of the controversy regarding the Section report could be resolved if rather than recommending nonanatomic teeth for all three types of occlusions, and for improving emotional health as is presently in the report, "if we could list the advocates and advantages of nonanatomic teeth and also the advocates and advantages of anatomic teeth, and list documentation for certain advantages, it would be easy to add to the report and we would have the concepts of both groups, because they represent two different opinions." He added "that if there were thirteen different people in this Section, they might have come up with somewhat different conclusions depending on how many advocates of each category were members of the Section. A balanced membership could probably have made such a list [mentioned above] rather than recommending one type of tooth for all situations."

Zander withdrew his motion to accept the introduction and summary statement. The second was also removed. Zander then made a motion that the entire report be accepted. This new motion was seconded by Shipmon. Discussion continued for some time without resolution of the motion. Zander finally removed his second motion and Shipmon withdrew his second.

Asgar suggested that the approval of Zander's motion to accept the introduction and summary statement would at least provide a report for publication. He said that "once the introduction and summary statement have been disposed of, the members of the General Assembly could then address themselves to the remaining contents of the report." The suggestion to accept the introduction and summary statement was placed in the form of a motion and seconded. The members of the General Assembly approved the motion.

Hickey asked if there was a mechanism available to the members of the General Assembly for further revision of the remaining portion of the report followed by a mail ballot regarding its acceptance. Lang responded that such a mechanism was not feasible and would not be in keeping with the format of the Workshop.

Perry felt that this was the time to have a vote between those who are practicing Prosthodontists and who are faced with the problem of constructing dentures for patients who have no teeth, as opposed to the Periodontists and the teachers and researchers and those who do very little work in a practical way with their patients. He added, "Lets bring this motion to a vote and pass it in honor of the work of that Section, because what they have said is in no way a deterrent to the comfort and use of complete prosthodontic appliances by their patients."

Shipmon then moved to accept the remaining portions of the Section report as read. This motion was seconded by Bell. Following a close voice vote, parliamentarian Ostrander called for a standing vote. The motion was passed.

SECTION V

# Dental Materials as Related to Complete Denture Occlusion

## Review of Literature

Physical Properties of Dental Materials as Related to Complete Denture Occlusion

*M. Kamal El-Ebrashi*
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The Effect of Materials, Design and Changes in Dentures on Bone and Supporting Tissues

*Robert G. Craig*
*Professor and Chairman*
*Department of Dental Materials*
*School of Dentistry*
*The University of Michigan*
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## Section Report

## General Assembly Discussion

# REVIEW OF LITERATURE

## Physical Properties of Dental Materials as Related to Complete Denture Occlusion

*M. KAMAL EL-EBRASHI*

Research activity in the area of dental materials has been extensive in recent years. Both applied and basic research studies were aimed to improve dental restorations and appliances. The clinical performances of materials have been covered in numerous reports, but the main challenge is to correlate physical, mechanical, and biological data with the clinical behavior of materials.

This review will be a critical assessment of the most recent research, covering the concepts which are the most controversial, along with the properties of materials and theoretical considerations that would seem to trace the more significant alterations in future clinical performances. Correlation between physical and mechanical properties of materials to occlusion will be emphasized.

### IMPRESSION MATERIALS AND TRAYS

The term impression material refers to that class of materials used to register or reproduce accurately the form and relationship of the teeth and oral tissues. Three different classes of materials are used for making complete denture impressions: **a.** elastic materials; those which remain in an elastic or flexible state after removal from the mouth; **b.** thermoplastic materials, or those which become plastic at higher temperatures and resume rigidity when the temperature is lowered to the mouth temperature; and **c.** rigid materials, or those which set to a rigid consistency.

The area of impression materials appears to be getting the average attention it enjoyed in previous years in the dental literature. No new types of impression materials or major alterations in technics have been developed during the past five years.

Basic studies include further investigation of the setting mechanism of both polysulfide polymers and silicone rubber materials. The mechanical properties of elastomeric impression materials and their relation to clinical usage has been reported *(Braden, 1966; Braden and Elliot, 1966; MacPherson, Craig and Peyton, 1967; Ozaki, 1965)*.

Ozaki *(1965)*, and Koan-Fuei, Kao, and Hashimoto *(1968)* investigated the setting process at room temperatures. Dental silicone rubber impression materials were compared. Both double-mix and triple-mix materials had a comparable amount of distortion. The setting time, however, was longer for the double-mix type. On comparing the elastic properties, the silicone rubber materials were found more elastic, and polysulfide rubber base and alginate were inferior (in that order). The elastic properties of all types of impression materials after storage were superior under low temperature and high humidity, as compared with those stored under high temperature and low humidity *(Braden and Elliot, 1966)*.

The rheology of elastomeric dental impression materials was investigated by Chong *(1971)* using a reciprocating rheometer. The viscosity changes in the setting material were recorded continuously and graphically. Rheology of elastomeric materials deserves more research.

Maintenance of the attachment of polysulfide material to a rigid impression tray is necessary in order to achieve optimal accuracy in the impression. Ellam and Smith *(1966)* demonstrated that an adhesive which becomes tract-free before the tray is filled gives superior bonding of the material to the tray. Since bond strength was higher with a more rapid loading rate, the rationale for "snap" removal of the impression received further support. Bliss and Saggs *(1967)* have shown that deformation takes place if the impression tray is twisted during removal.

Some photoelastic simulation of mercaptan rubber impression materials was reported *(Collard, Srandlee and Caputo, 1970)*. No dimensional analysis equations were used for the simulation in that study. Accuracy of impressions made with elastic impression materials received a great deal of attention *(Shippee, 1966; Wilson, 1966; Basset, Vander Heide and Smith, 1969; Shevlin, et al., 1970; Podshadley, et al., 1970; Asgar, 1971)*. Most of these reports used the conventional methods, but lacked scientific experimental design techniques. Some report that silicone is superior to other elastic impression materials, and others claim that mercaptan rubber is superior. Some correlation has to be established between setting time, temperature, humidity, tray adhesives, dimensional stability, and the accuracy of dies made from elastic impression materials.

Stackhouse *(1970)* reported that generally more uniform dies were constructed from silicone than from mercaptan rubber. Since he used perforated trays that are not used in making impressions for complete dentures, the report is not applicable to complete denture construction. The classical statement of Peyton, *et al.* *(1968)* is still significant. They wrote that, "both the mercaptan and silicone materials have been much improved. Each group has some advantages and disadvantages. The mercaptan polymers have been found to be more reliable in clinical use than the silicone materials produced so far. They are strong, relatively stable, elastic impression materials, which when correctly handled, give excellent results."



On studying dimensional accuracy and stability of polysulfide and silicone rubbers, it was found that both materials will shrink during curing *(Asgar, 1971)*. Two recognized methods have been established for the polymerization shrinkage of rubber base materials, namely the restricted method and the free method. It was found that the curing shrinkage of rubber impression material measured by the free (floating) method is about twice as much as that measured by the restricted method. The curing shrinkage of the silicone type is greater than that of the polysulfide type. Curing shrinkage of both types does not terminate at the time of removal from the mouth, but continues for a long period of time. Polysulfide rubber is more stable in dimension and shrinks less during curing in the first twenty-four hours than does silicone rubber.

Irreversible hydrocolloids have been studied by various methods. Elastic recovery from compressive strains was studied by Makinson *(1971)*. An optical method to replace the mechanical system was used. In most instances, values obtained for permanent deformation were less than those obtained from the optical method. This may be due to large strains at low stresses for these materials. It was noted that after deformation, an alginate impression should be allowed to recover before pouring the cast, and that for large undercuts, alginates may not be suitable. Bliss and Saggs *(1967)* found that a thin mix of alginate proved to be more susceptible to permanent deformation than a thick mix. Tear strength was higher and permanent deformation lower, under rapid loading, thus the importance of rapid removal of the impression from the mouth is reaffirmed. Walter *(1971)* studied fifteen alginate impression materials. He found that the materials which demonstrated the least ability to reproduce undercuts without rupturing were the materials which showed the least strain in compression. Walter's work showed that there is a lack of research of the tensile properties and behavior of alginates.

Other investigators *(Smith and Wilson, 1965; Wilson, 1966; Morrow, et al., 1971; Buchan, 1963; Chong, M., Chong, J. and Docking, 1970)* studied elastic recovery, other properties, and technics related to alginates. The compatibility of alginates and dental stones was studied by Morrow, *et al.* *(1971)*. It has been recommended that the mix of plaster or stone can be started by an assistant while the impression is being rinsed and dried. The poured cast and impression should be covered with wet paper toweling or should be placed in a humidor at 100 percent humidity to prevent drying of the alginate while the stone is setting.

Although the alginate impression materials are sufficiently elastic for clinical use and possess higher compressive strength values than the agar type, they tear more readily than do agar hydrocolloids, especially in thin sections. Close adherence to the manufacturer's directions specifying water to powder ratio, mixing time, water temperature, and leaving the impression in the mouth two to three minutes beyond the gelation time would help in forming clinically acceptable impressions. Should the water content of alginate gels be altered either by evaporation or syneresis, distortion of the impression will result. The alginate impression, like the agar impression, should be poured as soon as possible following removal from the mouth. Hydrocolloid impressions cannot be electroplated successfully. In general, all of the precautions which apply to the handling of alginates apply also to the agar hydrocolloids. Alginate impression materials are considered to be more sensitive to variables of manipulation than the agar impression materials.

Reversible hydrocolloids did not get enough attention in the last decade. Although they are seldom used in complete denture procedures, they are still excellent impression materials if properly manipulated. Panchokha *(1969)* reported on the physical properties of duplicating hydrocolloid compounds. The accuracy and dimensional stability of reversible hydrocolloid impression material has been studied by numerous investigators. In general, it has been found that if care is exercised in liquifying and tempering the hydrocolloid when properly forming the impression, and if the impression is poured immediately after it is removed from the mouth, clinically accurate results are obtained. There is no satisfactory method for prolonged storage of such impression because of the occurrence of imbibition and syneresis, and the fact that dental impressions have varying contours and thicknesses. The degree of dimensional change occurring is different throughout the impression. The water content of hydrocolloid gel may be altered by syneresis. When syneresis occurs, an exudate (consisting of water and salts from the agar gel) forms on the surface of the impression and causes shrinkage of the hydrocolloid impression. Syneresis is different from the loss of water by evaporation; syneresis takes place even during the storage of the impression in 100 percent relative humidity.

The physical properties of zinc oxide-eugenol pastes were reported *(Myers and Peyton, 1961; Asgar and Peyton, 1954)* as well as the effects of temperature and water on the setting time. The setting times were reduced by increasing the zinc oxide to eugenol ratio, by increasing the temperature, and by increasing the spatulation time. The addition of water to zinc oxide-eugenol pastes is not advisable as a means of controlling the setting time. It is a recognized fact that varying the mixing proportions of the zinc oxide and the eugenol pastes has little effect on the resulting values for physical properties. Erratic results were obtained for values of setting time, hardness, and strength in a study by Hempton and Bevan *(1964)*.



Zinc oxide-eugenol pastes are used for functional impression materials in complete denture prosthodontics. For functional impressions, the material should flow and not recover, that is, it should be plastic or viscous. Moreover, if the impression is to be completed in a short time, it is necessary that the material should reproduce the mucosal surface rapidly. If the material is to be left in the mouth for a prolonged period, it is necessary to have less flow; therefore, a harder material is required. This theoretically critical controversy must be resolved if truly functional impressions are to be made in complete denture prosthodontics.

Plaster impression materials were rarely researched in the last ten years. Although these materials are considered adequate materials, they suffer from the necessity of applying a thin film of separating media such as soap, alginate, or sodium silicate, to the impression prior to pouring the cast. There is no A.D.A. Specification for plaster of Paris impression materials.

Little research has been conducted during the last few years on dental impression compounds *(Combe and Smith, 1965)*. The principal reason for this lack of research to improve these materials is probably the decline in their use caused by the development of the various types of elastic impression materials.

Acrylic resin is still the most popular material for the construction of custom impression trays *(Bailey, 1955)*. The new disposable tray systems introduced in recent years has decreased the interest in research of new tray materials.

It has been found that the accuracy of casts made from rubber impression materials also depends upon the bulk of the material used. Rubber impression material behaves in an opposite manner to that of the hydrocolloid impression material. Increasing the bulk of the material decreases the potential of distortion and tearing of the hydrocolloid impression. Too small a bulk of rubber material also may cause some distortion of the impression at the time of removal from the mouth. A thickness of 3 to 4 mm. of the rubber impression material is usually recommended. The bulk of the rubber material also should be uniform over the entire area *(Asgar, 1971)*. Rubber impression materials should not be used with tray compound material because some of the chemicals in the impression may soften the compound, causing a lack of support of the impression, resulting in distortion of the impression.

## MODEL AND DIE MATERIALS

Dental stone, plaster, amalgam, silicophosphate cement, electroplated silver and copper, and casting investments are some of the materials used to make casts or dies from dental impressions. The accuracy of stone dies made from rubber impressions were studied by Stackhouse *(1970)*. The stone dies poured successively from the same rubber impression became increasingly shorter in length and thicker in diameter. His study compared stone dies cast from one thiokol and three silicone rubber impression materials. Newman and Williams *(1969)* have found that improved dental stone, along with other stone dies and metal dies, have comparable strength and accuracy. Harcourt and Grant *(1971)* studied the surface crystal morphology of gypsum using transmission and scanning electron microscopes. A wide variation of crystal morphology was evident and was related to changes in the water-powder ratio and to the nature of the chemical additives. Sodium chloride additions produced the greatest deviations from the normal shape of the gypsum crystals, where potassium sulfate additions tended to produce clusters of long slender crystals. Large coarse crystals resulted from borax additions. The chemical additions produced variations in the setting times and expansions, but no definite relationships among these values and crystal morphology could be established.

Jørgensen and Kono *(1971)* found that the porosity of nonvacuum treated stone is about 1.07 percent, whereas after vacuum treatment it is reduced to about 0.6 percent. Vacuum treatment results in an increase of the compressive strength of approximately 20 percent at a water-powder ratio of 0.21. This effect is reduced at higher water-powder ratios.

Combe and Smith *(1971)* introduced lignosulfonates into dental stones. These additions produce superior models and die materials that are compatible with dental impression materials. Lignosulfonates have significant effects on autoclaved calcium sulfate hemihydrate; i.e., reduction in water requirements, retardation of setting time, an increase in compressive and tensile strength, an increase in hardness, and an increase in linear setting expansion. Stones containing 99.47 percent hemihydrate, 0.33 percent commercial lignosulfonates, and 0.20 percent potassium sulfate appeared to be the most suitable for dental use. The mechanical properties were superior to those of existing stone.

The surface hardness of stone was improved by impregnating stone with acrylic resin, but there was some loss of die accuracy *(Eshleman, 1971)*. The comparison of the kinetic curves with Gillmore initial setting times revealed that the amount of surface-reacted product necessary for the mass to withstand penetration increased with increasing liquid-powder ratios. Increasing accelerators caused the plaster structure to weaken *(Harcourt and Lautenschlager, 1970)*.

The relation between compressive and tensile strength was independent of the water-powder ratio employed *(Jaoa and Chevitaresse, 1968)*. X-ray diffraction methods were employed to investigate setting reactions of gypsum materials *(Lautenschlager, Harcourt and Ploszaj, 1969)*. Other properties were reviewed in recent years, and the mystery of chemical behavior of gypsum is almost completely solved *(Lautenschlager, Harcourt and Ploszaj, 1969; Williams and Smith, 1971; Docking, 1958; Toreskog, Phillips and Schnell, 1966; Gettleman and Ryge, 1970; El-Tannir and Imam, 1969; Lautenschlager and Corbin, 1969; Ryge and Fairhurst, 1956; Mahler, 1951)*.



The optimum results with dental stones are obtained when care is directed to measuring the correct water-powder ratio, spatulating for the recommended time, allowing forty-five to sixty minutes to pass before removing from the impression (depending on the particular stone), and waiting approximately twenty-four hours if the full strength of the cast of die is desired.

## BASEPLATE MATERIALS

Wafers of thermoplastic materials are made in suitable gauges to be heated and conformed to casts under pressure. When the material has returned to the hard state on cooling, and the excess has been trimmed away, the resultant forms serve either as individual impression trays or trial bases. The material, when softened and pressed against the cast, should stay dimensionally stable, and should not spring back on the release of the pressure. The most generally used wafers for this purpose are mixtures of shellac and filler *(Nagle, Sears and Silverman, 1962)*.

Burnett *(1968)* described a technic for constructing a trial denture base. A combination of soft and hard resins are used, by first placing the soft resin (COE-SOFT) in undercut areas. Using the "dust-on" method, the autopolymerizing acrylic resin is applied over the cast and the soft resin. The resins are cured under air pressure, in a pressure chamber. This type of baseplate may be used without danger of scarring the master cast.

Sometimes the baseplate materials that are used for construction of trial denture bases are stabilized using aluminum foil and zinc oxide-eugenol paste *(Silverman, 1957)*.

It seems desirable to develop a material which is essentially an impression material, and is capable after making the impression of the patient's oral tissues, to be transformed through some system to a denture base material. This will eliminate several steps, namely, casting the master impression, the construction of a trial denture base, and then the transformation of the temporary base into a permanent denture base material. Registrations of jaw relations, functional usefulness, durability, tissue adaptability, and errors of processing may be significantly reduced.

## WAXES

Procedures in complete denture prosthesis cannot be carried out without the use of wax in one of its many forms. The tasks that these different waxes perform (and, therefore, their properties) vary greatly. Little is reported in the dental literature about the basic nature, compositions, thermal, and mechanical properties of the dental waxes currently employed in a variety of applications. All waxes exhibit a relatively high degree of flow when subjected to compression forces, with some having greater flow than others. The thermal expansion of waxes is excessive in comparison with other dental materials. All waxes exhibit a tendency to warp or distort, and this quality is influenced by the existing temperature *(Peyton, et al., 1968; Ohashi and Paffenbarger, 1969; Craig, Eick and Peyton, 1966; Craig, Eick and Peyton, 1965; Craig, Eick and Peyton, 1967; Skinner and Phillips, 1967).* When certain waxes are properly blended, the ability of the new combination to perform a given function is often enhanced due to modification of properties. The expansion and contraction of dental waxes is pronounced with changes in temperature since dental waxes have the largest coefficient of thermal expansion of any restorative material in dentistry.

The measure of flow of waxes below the melting point is really a measure of the degree of plastic deformation of the material at a given temperature. A wax which becomes permanently deformed under stress (flows) exhibits the quality of plasticity, whereas the amount of recovery of the wax to its original shape (following the removal of the stress) indicates its degree of elasticity. On the other hand, the ability of the wax to be permanently deformed without rupture is a measure of its ductility, and is closely related to the qualities of flow and plasticity. Like flow, the ductility increases as the temperature of the wax is increased.

Baseplate wax is used extensively in prosthodontics. Generally the composition is assumed to be 70–80 percent paraffin base waxes or commercial ceresin, 12 percent beeswax, 2.5 percent carnauba, 3 percent natural or synthetic resins, and 2.5 percent microcrystalline or synthetic wax *(Peyton, et al., 1968).* Type I baseplate wax, which exhibits the greatest flow, should not fracture when bent double on itself at 70° F. Type II baseplate wax, possessing the least flow, should not fracture at 80° F when bent double. There is much residual stress within the baseplate wax holding and surrounding the teeth of a waxed denture. These stresses result from differential cooling. Therefore, the waxed dentures should not be allowed to stand for long periods of time, especially when subjected to elevated temperatures.

Boxing wax should be pliable at 70° F and should retain its shape at 95° F. In a broad sense, this defines its lower temperature limit of ductility and flow. It is desirable to have a boxing wax that is readily adaptable to the impression at room temperature. This property reduces the chance of distortion of the impression from the standpoint of both temperature and the stress involved in the boxing procedures.



Impression waxes are formulated for use as an impression material, exhibiting high flow and ductility, and with the ability to distort readily when withdrawn from undercut areas. The impression waxes may be divided into two classes, the corrective waxes and the bite waxes. The corrective waxes are usually used as a wax veneer over an original pattern. The bite wax is used in bulk form; for example, beeswax has been used in certain prosthetic procedures for many years. In general, both types are soft and plastic at mouth temperature, and yet possess enough body to register and retain the bite detail. Finally, while the information which is known about waxes generally is being used skillfully, there are numerous problems which remain to be solved.

## DENTURE BASE MATERIALS

The Academy of Denture Prosthetics has outlined the requirements of an ideal denture base in hopes of stimulating interest in, and giving direction to, the area of denture base materials *(Atwood, 1968).* The qualities were divided into seven arbitrary categories: (1) physiologic compatibility, (2) acceptability to patients, (3) functional usefulness, (4) hygienic factors, (5) durability, (6) adaptability to clinical problems, and (7) cost factors. The report was ambitious enough to suggest a denture base molded directly to the oral tissues, i.e., the impression material would become the base. Grant and Greener *(1967)* found that flexure strength of polymethyl methacrylate could be improved by reinforcement with sapphire whiskers.

The properties of polycarbonates proved to be comparable to polymethyl methacrylates with respect to some properties *(Stafford and Smith, 1967).* Impact strength was higher and water sorption lower. Short term clinical observations of twenty-five polycarbonate dentures reported no fractures. The dentures lost some of their polish. Lyon *(1969)* investigated the flow properties of four denture base polymers at various temperatures and load ranges. Three resins were heat-cured polymethyl methacrylates and the fourth was a polycarbonate (Andoran, Bayer, West Germany). Flow of heat-cured resins, under stresses which could be developed by differential thermocontractions within a gypsum mold, took place at temperatures as low as 60° C. It was found that in order to reduce the dimensional changes and the internal stresses within denture bases, it is advisable to cool the flask as slowly as possible from the processing temperatures to 60° C, then any rate of cooling will not impair the accuracy. The polycarbonate material showed little or no flow, so that greater dimensional changes could be expected on removing a denture from the flask.

Civjan, *et al.* (1968) reported on a pourable type resin. The powder is a polymer of high molecular weight and a small particle size. Poured denture bases (Shepard, 1968) appeared to fit casts more accurately than those formed by compression technics. Swartz (1966) found that aluminum was suitable for denture bases, and if handled properly, retention of aluminum dentures was superior to that of polymethyl methacrylate bases. Geissler (1969) also reported that aluminum-bronze could be used for constructing complete denture bases. Alloys of copper containing 10 percent aluminum, as well as nickel, iron and manganese in small amounts, were used. Alloys of these materials were less dense than chrome-cobalt, but aluminum-bronze and gold had the same hardness. Limited clinical experience was reported using these new alloys.

Waters (1968) studied the mechanism of fatigue fracture of acrylics. Fatigue failure was due to crack propagation originating either from a flaw or an inclusion in the denture base material. Kelly (1967) investigated cyclic loading of heat-cured and autopolymerized denture resins, and found that heat-cured materials were more resistant to flexure fatigue. A limited number of the fractured heat-cured samples were repaired with autopolymerized resin and retested. The fact that some of this group fractured through the heat-cured resin suggests that the previous flexing had impaired the strength of the heat-cured material. Hargreaves (1969) studied the prevalence of fractured dentures. An analysis of the cause of fracture in ninety-one dentures (partial and complete) showed sixty-eight percent had broken by the end of three years of usage, with a greater proportion being partial dentures. Forty percent of the dentures were broken during mastication, there being twice as many complete dentures as partials.

There is no evidence in the literature that the physical properties of acrylic resins deteriorate with age. Berry (1957) suggested that there was some correlation between midline fracture of upper complete dentures and occlusal wear of acrylic resin teeth. It was noted that if upper teeth are set too far buccal to the lower teeth, an anti-Monson curve of occlusal wear develops and leads to fracture of upper dentures.

Stafford and Smith (1968) studied some properties of polymethyl methacrylate polymers. It was shown that polymethyl methacrylate polymers had low tensile strength, particularly under conditions of impact and fatigue.

Four materials; Kallodent (PMM containing about 0.9 percent benzoyl peroxide and pigment), Luxene (copolymer of vinyl chloride, vinyl acetate, and methyl methacrylate supplied as a gel material), and Impak (modified PMM containing 0.3 percent cross linking agent and a small amount of polystyrene resin), and Andoran (which is a linear polyester of carbonic acid in which the carbonate groups recur in the polymer chain) were investigated. All materials showed lower strength after water sorption, and their tensile strengths were of similar magnitudes in decreasing order; Kallodent, Luxene, Impak, and Andoran.



Jones, Wilson and Osborne (1970) studied the impact properties of porcelain, acrylic, polystyrene, and cellulose acetate. The authors did not use the conventional pendulum machine, but developed a method for determining the transverse strengths of small specimens (3 × 2 × 20 mm.). It was found that the force required to break a specimen in bending increased as the rate of loading increased from 0.017 mm. per second to 135 mm. per second (the determined chewing speed). Deflection of transverse specimens decreased as the rate of loading increased. Materials became stiffer at higher rates of loading. The energy required to fracture a specimen generally decreased as the rate of loading increased. Therefore, in the determination of transverse properties of dental materials, the rate of loading should be similar to the chewing speed, that is 135 mm. per second.

Paffenbarger, Sweeney and Bowen (1967) reported bonding of porcelain teeth to resin denture bases by treatment of the teeth with a silane coupling agent of the type used for bonding inorganic fillers to the matrix in composite resins. Some residual stress was evident in the process which appeared to strain the porcelain teeth, sometimes causing fracture during or after processing. Semmelman and Kulp (1968) and Myerson (1968) investigated this phenomenon further and found that the strength of porcelain teeth (bonded to the denture base) was reduced. The reduction in strength was attributed to shear stress induced by shrinkage of the resin during cooling. Lower processing temperatures produced less flaws in the porcelain, and little or no weakening of the porcelain occurred when it was bonded to autopolymerized acrylic resin. Thus, the difference in thermal expansion of the resin and the porcelain appeared to be the causative factor.

Deposition of a microlayer of silica (Boucher, et al., 1968) on the surface of PMM has been shown to increase its wettability. Theoretically, such treatment should improve the adhesive characteristics of denture base materials. After a clinical investigation of the (Durabond) process, it was found that the force required to dislodge mandibular dentures was greater after the silica layer was deposited on the denture surface.

Resilient liners (Bascom, 1966) are still to be considered in the category of temporary denture liners. Plasticized acrylic liners (Sauer, 1966) bleach out and gradually lose their resiliency. Silicone rubber materials remain soft, but become bleached, stained and wrinkled, and some evidence of dimensional change was reported (Woelfel and Paffenbarger, 1968). Candida albicans were observed on many silicone rubber liners after eighteen months of service. *In vitro* studies by Gruber, Lucatorto, and Molnar (1966) indicate that the silicone rubber materials support the growth of this organism. Williamson (1968) reported that the material itself does not support the growth of this organism. Further studies are indicated to investigate the effect of incorporation of a nontoxic fungicide and the divergences of the results.

In a study by Turrell *(1966)*, it was found that there was no difference in tissue response to autopolymerized and heat-cured denture resins. The changes in tissues beneath resins were similar to those observed under Vitallium.

Combe *(1969)* reported on the development of a radiopaque acrylic resin by the incorporation of about 8 percent barium sulphate. An increase over 8 percent will cause deterioration of the mechanical properties of the polymer. Additives investigated include lead acetate, powdered gold, magnesium oxide, barium fluoride, and barium acrylate.

LePera *(1968)* suggested two procedures for avoiding some of the changes that occur in the processing of acrylic resin dentures. Freezing the mold before packing will minimize processing changes, and the use of a central exhaust for the escape of excess resin will avoid increasing the vertical dimension of dentures during processing. LePera described a special flask for use with the central exhaust method. He also outlined the technique for its use. A considerable number of studies have been made of the dimensional changes occurring during processing and storage of dentures *(Mowery, et al., 1958; Woelfel, Paffenbarger and Sweeney, 1962; Leaders and Pearson, 1952; Smith, 1962; Woelfel, Paffenbarger and Sweeney, 1960; Woelfel and Paffenbarger, 1959; Anthony and Peyton, 1962; Paffenbarger, Woelfel and Sweeney, 1962; 1963a; 1963b; A.D.A. Council on Dental Materials and Devices, 1968–1969; Paffenbarger, Woelfel and Sweeney, 1965; Rupp, Bowen and Paffenbarger, 1970; Hamrick, 1962; Jennings, 1970; Woelfel, 1971)*. The main variation in the values obtained is the amount of linear expansion that results after the dentures are stored in water. This probably arises from variations in the amount of stress developed in processing, which produces different amounts of curing shrinkage, warpage, and expansion in water for dentures of various thicknesses and shapes. The most uniform results have been obtained across the posterior region of dentures. In general, heat-cured dentures immersed in water show a linear expansion in the region of 0.1 to 0.2 percent, which partially, but not completely, compensates for the processing shrinkage of 0.3 to 0.5 percent. The net linear change in this type of denture can vary from a shrinkage of 0.1 to 0.4 percent *(Munns, 1962; Laney, 1970)*. There is always a concern regarding what a net shrinkage of 0.1 to 0.4 percent represents clinically. A number of other steps in the construction of a complete denture involve dimensional inaccuracies, such as making the impression, pouring the cast, and preparing and investing the waxed denture base. When only the fit of the denture on the cast is considered, however, a net linear shrinkage results in the denture fitting only on the sides of the flanges. The oral tissues would conform to the topography of the dentures, since problems of settling are also encountered.



It was found that the greatest linear changes took place when the cured denture was removed from the gypsum cast. Upper dentures changed less than lowers, thick upper and lower dentures changed less than thin ones. Conventional acrylic resins processed with conventional techniques of compression molding were just as stable in dimension as the special resins (vinyl, polystyrene and epoxy resins) and techniques investigated, and reproduced the wax model denture just as accurately. Probably more than ninety-five percent of complete dentures are made today using one of the acrylic resins. However, a number of other materials are occasionally used in complete denture prosthodontics such as metals, plastics other than acrylic resin, porcelain, and resilient liners combined with hard plastic denture bases.

Metal denture bases are thought to have several advantages over acrylic resin bases. Thermal conductivity, lack of bulk with more strength, and dimensional stability are advantages of metal bases, whereas high cost, specific gravity, and the inability to be rebased are the chief disadvantages. Chrome-cobalt, gold, and aluminum bases are used in upper dentures more than in lower dentures *(Woelfel, 1971)*.

Several plastics have been tried as denture base materials. Nylon, has proved to be almost entirely unsatisfactory owing to its poor ability to resist the oral conditions. It swelled from absorption of water and discolored after six months. Epoxy resin was found unsatisfactory owing to a high rate of water absorption. Polycarbonates require elaborate processing equipment and high molding temperatures to produce dentures with few, if any, advantages over acrylic resins. When polycarbonates were compared with acrylic resin dentures, the polycarbonates showed greater distortion from water absorption, higher flexibility, lower hardness, and lower adhesion to acrylic resin teeth. Vinyl acrylic copolymer (Luxene 44) and polystyrene resin (Jectron) have greater strength than the acrylic resins, but neither the vinyl nor the polystyrene resins will reproduce the impression surface as accurately as acrylic resin *(Woelfel, 1971)*.

Since the introduction of acrylic resins, several significant improvements have been developed which make them even more versatile. Most acrylic resins today contain a cross-linking agent, such as glycol dimethacrylate in the monomer, and this gives resistance to crazing which was a problem with the early acrylics. It is also noted that autopolymerized acrylic resins have better dimensional accuracy, and repairs were greatly simplified. The so-called "fluid resins" have gained a small degree of popularity in the past few years. Basically, they are a modified type of autopolymerizing acrylic resin. These resins harden in six to ten minutes, preferably with the flasks placed in an air pressure chamber (20 to 30 psi) or in a centrifuge which minimizes porosity *(Woelfel, 1971)*.

Finally, the denture of the future may be made of an extremely thin composite plastic or metal, or yet undiscovered form of plastic. The future denture might be cemented or glued into place, eliminating the necessity of palatal coverage. It might even have mechanized grinders to assist in pulverizing tough foods, or have an automatic fluid exchange within the tissue-bearing surface to provide continuous uniformity of contact or distribution of the forces on the mucosa *(Woelfel, 1971).*

## TOOTH MATERIALS

Porcelain teeth, acrylic resin teeth, and acrylic resin teeth with metallic inserts are the types of posterior teeth most commonly used in prosthetic dentistry. Porcelain teeth are used mostly in complete dentures. Porcelain and acrylic resin teeth are used with equal frequency in removable partial dentures *(Sowter, 1962).* The advantages and disadvantages of opposing porcelain teeth and acrylic resin teeth have been summarized by Davies and Pound *(1966).* To offset these long-recognized problems, Sears *(1956, 1957),* Myerson *(1957),* and Jankelson *(1962)* advocated the use of acrylic resin teeth in one dental arch opposed by glazed porcelain teeth in the other dental arch. Hardy *(1951)* and Yurkstas *(1963)* advocated the use of ribbon-like metallic inserts made of chrome-cobalt alloys in nonanatomic acrylic resin posterior teeth to improve chewing efficiency and comfort.

Leathers *(1966)* used metallic surfaces against nonanatomic porcelain teeth in the opposing dental arch. Cutterbars with geometrically designed occlusal surfaces were developed to improve masticatory efficiency. These metal inserts are usually used in the mandibular dental arch and are opposed by nonanatomic porcelain teeth. Their use is supposed to improve comfort and efficiency *(Bader, 1955, 1957; Potter, Appleby and Adams, 1966).*

Selecting posterior teeth to oppose natural teeth, especially those with extensive metallic restorations, poses several problems. Porcelain teeth will provide efficiency but may also cause extensive wear on the opposing masticatory units. Acrylic resin teeth eliminate the problem of wear on the natural teeth, but clinically they seem to be less efficient. The use of gold or chrome-cobalt occlusal surfaces has been reported *(Davis and Pound, 1966; Shultz, 1951; Wallace, 1964).* It has been written that this type of anatomic occlusal surface provides the efficiency of porcelain teeth and the comfort of the acrylic resin teeth. The placement of large silver amalgam restorations in acrylic resin posterior teeth seems to be a simple method to produce a more natural feeling, and to improve efficiency. Sowter and Bass *(1968)* recommend this technic when the acrylic resin teeth must be used because of limited interarch distance or when the denture opposes extensive metallic restorations.

Tillitson, Craig and Peyton *(1971)* reported friction coefficients for a variety of material couples. The relative abrasive wear of materials followed the order of their hardness, with the exception of amalgam, the deviance of which probably resulted from transfer of amalgam to the abrasive wheels. Values reported for the coefficient of friction may be a function of load, sliding velocity, transfer of one material to another, wear particle accumulation, or the presence or absence of water on the surface. Comparison of material couples on both wet and dry conditions revealed that water sometimes functioned as a lubricant and other times acted to increase the friction. One of the factors in lower loads which caused less friction was the ductile behavior of materials under these conditions. This report will have a wide impact on occlusion in complete dentures and more attention should be paid to the setting of posterior teeth in opposite dental arches made of different materials. The inclusion of metal inserts, such as gold or chrome-cobalt alloys against natural and/or artificial acrylic resin or porcelain posterior teeth, would tend to increase friction, since the relative abrasive wear of materials generally followed the order of the hardness of the materials. This was the first experimental study which tested friction and wear under many variables, and included the use of simulated mouth conditions. Studies reported in the dental literature have been limited to wear measurement with simulated tooth brushing methods, or on prosthetic teeth mounted on an articulator *(McConnell and Conroy, 1967; Cornell, et al., 1957).*



Moses *(1968)* reported that chewing efficiency of complete dentures is dependent upon the surfaces of teeth and their arrangement, and upon the structures of the basal seat under the denture base. Cusps on complete denture teeth tend to cause the bases to shift, and they are not necessarily more efficient than chrome-cobalt cutters or gold cutters.

Acrylic resin teeth have satisfactory mechanical properties, such as; compressive strength (11,000 psi), elastic modulus ($3.9 \times 10^5$ lbs./in.$^2$), elastic limit (8000 lb./in.$^2$) and hardness (18–20 KHN) *(Sowter and Bass, 1968).* These mechanical properties are low when compared to other restorative materials, or to human enamel and dentin.

The physical properties of porcelain teeth may be shown by comparing them with the properties of acrylic resin teeth. These properties, however, are often so radically different that they cannot be measured with the same equipment or be compared qualitatively. The flexural strength of dental plastics is unquestionably superior to that of the dental porcelains. The high impact strength of plastic gives it a definite advantage. Vacuum firing has improved the fracture resistance of dental porcelain by about 50 percent, but this does not preclude the possibility of fracture due to sudden shock. Tones *(1971)* obtained strength measurements for a large number of dental porcelain specimens. The persistent and characteristic scatter in strength values obtained for different types of materials indicate the wide variance in composition and strength.

In conclusion, neither acrylic resin nor porcelain is an ideal material for the fabrication of artificial teeth. Probably some material with intermediate properties would be more desirable. Such a material should have higher hardness and abrasion resistance than acrylic resin, and greater impact strength or toughness than porcelain.

# The Effect of Materials, Design and Changes in Dentures on Bone and Supporting Tissues

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## DENTURE BASES

**PROCESSING CHANGES.** The selection of material for this section is based on the assumption that dimensional errors in the tissue-bearing surface of the denture are undesirable because of tissue changes, in spite of the many studies that have established that patients can tolerate linear dimensional errors considerably in excess of 0.5 percent. Also, because the errors related to the use of various impression materials have been previously discussed, this section will be concerned with dimensional changes after the preparation of the master model.

The properties of denture base resins have been described as early as 1939 by Sweeney. Subsequent articles described the properties of room-temperature activated acrylic resins *(Caul, Stanford and Serio, 1952; Peyton, Shiere and Delgado, 1953)*. A few years later the properties of self-curing repair materials were described by Stanford, Burns and Paffenbarger *(1955)*. More recently, Woelfel, Paffenbarger and Sweeney *(1963)* described the properties of twelve types of denture base resins. In general, the denture base resins can be described as relatively soft (Knoop Hardness about 20), rather flexible (elastic modulus 300,000–500,000 lbs./in.$^2$), moderately strong (15,000–20,000 lbs./in.$^2$ compressive and 7,000–10,000 lbs./in.$^2$ tensile strength), of relatively low impact strength (0.2–0.8 ft.lbs./in. of notch-Izod), low water sorption (2–4 percent), good color stability, and high thermal expansion (70–100 × $10^{-6}$/° C in the range of mouth temperatures). The glass transition termperature of the materials varies from 105° C for acrylic polymers to 80° C for vinyl polymers *(Braden and Stafford, 1968)*. The materials function as brittle plastics below the glass temperature and the polymer molecules have greatly restricted motion below this temperature. The water that is sorbed by the polymer serves as a plasticizer and causes a small reduction in the mechanical properties. The water also swells the polymer slightly which results in a dimensional expansion. Residual monomer remaining in the polymer after processing also functions as a plasticizer and reduces the mechanical properties.

Aluminum denture bases *(Lundquist, 1963; Barsoum, Eder and Asgar, 1968)*, electroformed metal palates *(Rogers, 1970)*, Cr-Co-Ni inserts *(Berry and Funk, 1971)*, and aluminum-bronze *(Geissler, 1969)* denture base materials also have been investigated.

The change in volume of many monomers of the acrylic type to polymers is about −20 percent, and based on a monomer concentration of about 25 percent, a volumetric change of about −5 percent of a linear change of −1.7 percent would be expected. Zero to −0.6 percent linear change is observed in practice. The differences observed are related to: **a.** the shape of the specimens, **b.** the difference in thermal expansion between the polymer and the investment, **c.** the temperature of processing, and **d.** the glass transition temperature of the polymer. Processed dentures have been shown by a number of investigators to vary in dimensions from the initial master model *(Mahler, 1951; Mowrey, et al., 1958; Ryge and Fairhurst, 1959; Anthony and Peyton, 1959; Woelfel, Paffenbarger and Sweeney, 1960; Anthony and Peyton, 1962; Peyton and Anthony, 1963; Paffenbarger, Woelfel and Sweeney, 1965; Woelfel and Paffenbarger, 1965; Pickett and Appleby, 1970)*. These studies have shown that increased vertical dimensions resulted from increased pressure on the acrylic resin, and decrease in hardness of the material used in the third pour of the investing procedure. Dimensional changes during processing also have been determined by measuring the distance between metal pins or marks on the denture and by measuring the contour of various cross-sections of the tissue-bearing surface of the denture. In general, the flanges of the dentures move in after the denture is removed from the stone model and therefore the denture cannot be completely reseated on the model. It has been found that the poorest fit is at the periphery, followed by the crest of the ridge and the center of the palate. Anterior-posterior sections showed that the dentures fit better in the anterior portion. The linear dimensional change, as measured from transverse sections in the second molar region, was about −0.6 percent for heat-cured acrylic dentures, −0.3 percent for room temperature cured acrylic dentures, and −0.6 to −0.8 percent for injection molded acrylic, vinyl acrylic, or styrene denture base materials.

That processed denture bases contain residual stress was demonstrated by a number of studies *(Horton, 1949; Woelfel, Paffenbarger and Sweeney, 1963, 1962)*. Heating the denture base materials above the transition temperature caused a release of stress and resulted in a change in dimensions, as evidenced by a further linear shrinkage in the transverse sections. Because this dimensional change will occur at temperatures of 60–90° C, patients should be advised to avoid cleaning dentures with very hot water.

Processed dentures change dimensions by simply storing them in water *(Woelfel, Paffenbarger and Sweeney, 1962; Anthony and Peyton, 1962)* since the polymers will absorb water, resulting in a slight amount of swelling. The absorbed water may evaporate if the dentures are allowed to dry out and the dimensional changes associated with absorption and dehydration are approximately equal. The absorption of water results in an outward movement of the flange of the denture, and as a result, the denture fits better. Acrylic dentures processed by heat and allowed to absorb an equilibrium amount of water are about −0.3 percent undersized compared to −0.6 percent just after processing. Vinyl acrylic and polystyrene denture base materials do not absorb water to as great an extent as acrylics, and thus remain about −0.5 percent undersized after soaking in water. As anticipated, in general, thick denture bases showed less dimensional change than thin bases and mandibular dentures showed greater dimensional change than maxillary dentures. Also, the injection methods, regardless of the polymer used, resulted in larger dimensional changes in processing than the comparable material processed by dough molding.



The accuracy of cast aluminum bases was measured with a surface meter and the results compared with heat- and room-temperature curing acrylic bases *(Barsoum, Eder and Asgar, 1968)*. The study reported that the aluminum bases were the most accurate, followed by room-temperature and heat-curing acrylic denture bases, although it is not clear whether the acrylic dentures were at equilibrium with water or whether the measurements were made at 37° C. Claims have been made *(Rogers, 1970)* that electroformed metal palates were more accurate than cast or swaged palates although no numerical evidence was presented to confirm this statement.

Until recently some form of gypsum had been used as the investing media in the processing of dental resins. The polymerization reaction for acrylics, however, will take place in the presence of agar or alginate hydrocolloid. A number of articles have been written about the procedure using an agar hydrocolloid gel mold *(Fairchild, 1967; Winkler, 1967; Shepard, 1967; Goodkind and Shulte, 1970; Winkler, et al., 1971a; Kraut, 1971; Grant and Atkinson, 1971; Winkler, et al., 1971b)*; the method has become known as the "fluid resin, or pour technique." The general concensus of these studies is that dentures processed by the fluid resin method are less accurate than those processed by heat or room-temperature methods. Kraut *(1971)* found the pour resins to produce dentures less accurate in the posterior region, the center of the palate, and on the palatal slope of the maxillary ridge. Winkler, *et al. (1971a)* found linear dimensional changes for pour resins in the molar-to-molar direction to be −0.3 to −0.7 percent after processing and −0.4 to −0.9 percent after storage in water for twenty-four hours at room temperature. The loss in vertical height was 0.11–0.26, 0.20–0.26 and 0.26–0.41 mm. for anterior teeth, premolar cusps, and molar cusps. Although the loss in vertical height was small, if the loss in upper and lower dentures are considered along with the selective grinding to balance the occlusion, the reduction will shift the occlusion toward the anterior unless it is compensated for by additional anterior clearance. In a later article, Winkler, *et al.* compared the use of agar and alginate investing media; the average molar-to-molar shrinkage was approximately the same regardless of whether agar or alginate was used (0.20 to 0.25 percent after processing, 0.55 to 0.57 percent after one day in water, 0.55 to 0.56 percent after one week in water, and 0.44 percent after thirty days in water). Vertical changes were small in the anterior region, −0.05 to −0.1 mm., and large in the molar region, −0.19 mm. with agar and −0.39 mm. with alginate. The authors wrote that the shrinkage shifts the pressures of occlusal contacts to the anterior teeth, resulting in trauma to the anterior residual ridge and loss of bone. When the fluid resin method is used, more anterior clearance should be provided. Alginate was found to be inferior to agar as an investing media because of difficulty in removing wax models, scuffing of the surface of the alginate, rougher surfaces, more voids, and adherence of characterization fibers to the alginate. Grant and Atkinson *(1971)* measured changed in height of the teeth when dentures were processed by the pour or fluid resin technique. More tooth movement resulted when the pour technique was used as opposed to conventional methods. They found two situations; one where an increase in the tooth height occurred in the molar regions only, and the second where the tooth height was lower in the anterior, and gradually increased toward the posterior. The former conditions resulted from a movement of the molars only, while the latter occurred because of the tilting of the cast.

Some of the problems of the pour technique are, or have been, solved by incorporating glycols in the agar which aid in the retention of the posterior teeth. Modifications in the particle size and distribution of the polymer powder have resulted in powder-liquid ratios of 3:1 with adequate fluidity for pouring the mix. Where retention of posterior teeth in the agar mold is a severe problem it may be necessary to lute the teeth to adjacent teeth with acrylic before processing the denture base.

Room-temperature-vulcanizing silicone rubber also has been used as an investing material *(Harcourt, Lautenschlager and Molnar, 1969)*. It is used as a liner over a gypsum material. A layer of silicone rubber is used against the denture which is supported by plaster or stone. One study *(Tucker and Freeman, 1971)* showed no statistical difference in dentures processed in silicone mold liners and gypsum based on the position of the incisal guide pin. Another study *(Reisbick, 1971)* showed discrepancies of 0.21 and 0.27 mm. and 0.17 and 0.19 mm. for two midline sections of an upper denture when silicone and stone were used; discrepancies of 0.11 and 0.18 mm. were measured for two ridge sections when silicone and stone were used. The author found significant differences for the ridges but not for the midline sections. The dimensional changes of an acrylonitrile and a polyamide denture base material that are fabricated by injection molding were reported by Choudhary *(1969)*. The acrylonitrile had a linear processing shrinkage of 0.13 percent, whereas the polyamide showed a shrinkage of 0.53 percent. On storage in water, the mean dimensional change was −0.27 percent for the acrylonitrile copolymer and −0.34 percent for the polyamide.



**CLINICAL CHANGES.** Woelfel and Paffenbarger *(1959)* followed the dimensional changes in a set of clinical upper and lower crosslinked acrylic dentures under a variety of conditions. The molar-to-molar and flange-to-flange processing shrinkage was about −0.4 mm. and this decreased to −0.3 mm. after three months of service and no further changes were noted up to nine months. No dimensional change was observed as a result of heating the dentures for thirty minutes at 180–190° F. However, boiling in water for fifteen minutes resulted in molar-to-molar shrinkages of 0.51 mm. and flange-to-flange shrinkages of 0.33 mm. Reboiling for thirty minutes resulted in no further change. The warped denture was serviceable and comfortable to the patient but heavy contact on the buccal surfaces of the tuberosities was observed by pressure-indicator paste; the next day considerable reduction in contact in these areas was noticed. Reflasking and reprocessing resulted in further shrinkages of 0.4 and 0.6 mm. in the molar-molar and flange-flange measurements; this warpage caused the patient some slight pain on insertion but none after insertion. Larger areas of impingement of the lateral sides of the tuberosities resulted. The denture was uncomfortable for several hours, but after wearing, the areas were relieved. Later insertion of this warped denture after wearing a new denture resulted in poor retention.

Woelfel and Paffenbarger *(1965)* later reported a clinical evaluation of sixty-three complete dentures made from eleven different plastic denture base materials. The dentures were worn from three to six years and they showed a gradual deterioration in: **a.** centric and eccentric occlusion, **b.** retention, **c.** stability, and **d.** condition of the oral tissues. The dimensional changes in the dentures could not be correlated with the above deterioration, but the deterioration was a result of changes in the hard and soft tissue. The lower dentures appeared to be as stable as the uppers and the tissue under each was in about the same condition. The average number of post-insertion adjustments was 2.5 and it was not related to the denture base material. Evidence indicated relining or rebasing should be done within three to five years with an annual evaluation. A more recent study by Woelfel and Paffenbarger *(1970)* reported the clinical results of a Vulcanite and an epoxy denture. Again, deterioration in serviceability was the result of tissue changes rather than major changes in dimensions of the dentures. The epoxy denture gradually expanded and some warpage occurred in the Vulcanite denture; the magnitude of these changes was about twice that usually experienced during normal processing, but the changes could not be correlated to clinical symptoms.

The dimensional stability of porcelain dentures was reported *(Choudhary,* *et al.*, *1964)*. No fluid absorption was observed up to ten months, and patients expressed satisfaction with respect to comfort, function, and esthetics. Tissue tolerance was excellent. The main problems were breakage when handled carelessly outside the mouth, and finishing and polishing of the porcelain bases.

The removal of calculus and stain from plastic dentures has been studied by several investigators *(Anthony and Gibbons, 1958; Nicholson, Stark and Scott, 1968)*. A number of cleaning agents were tried and a solution of sodium hypochlorite and phosphate was found the most effective. Cleaning would be accomplished by soaking, followed by very light brushing. Ultrasonic cleaners in combination with the above solution were evaluated and this method only slightly increased the loosening of deposits.

**REPAIR AND RELINING CHANGES.** The changes in contour of the tissue-bearing surface of dentures during repair were reported by Anthony *(1961)*. Heat-cured dentures exhibited considerable dimensional change when repaired by a heat-curing process, but relatively little change when repaired by a self-curing resin. The self-cured dentures showed practically no dimensional change regardless of whether they were repaired by either heat- or self-curing resins. Discrepancies as large as 0.01 to 0.02 inches were observed in the midline and periphery of a transverse molar-to-molar section when a heat-cured denture was repaired by a heat-curing resin, and as little as 0.003 and 0.001 inches were observed when a self-curing material was used. Total changes in nine selected areas in self-cured dentures repaired by heat- and self-curing resins were 0.009 and 0.006 inches, respectively.

Relining materials can be subdivided into two types; indirect and direct. The processing changes of indirect materials are essentially the same as those previously discussed for denture base materials. The physical and mechanical properties of direct, hard, self-curing denture reliners were reported by Brauer, *et al.* *(1959)*. These materials, when processed under clinical conditions, were porous and the mechanical properties lower than for regular self-curing denture base materials. The reproduction of the surface detail was adequate and no significant warpage or dimensional change was observed. However, these liners were recommended as temporary materials.

Smith, Lord, and Bolender *(1967)* found that processing in water at 100° F with air pressure over 10 lbs./in.$^2$ produced acrylic denture liners with optimum properties. They also showed that the space between the relined sample and the die was less than the space found under self-cured relined samples processed at 130° F, and heat-cured relines.

Relining techniques have been described that attempt to produce dentures with minimum occlusal error *(Shaffer and Filler, 1971; Christensen, 1971)*. Christensen *(1971)* evaluated a variety of relining procedures using the change in vertical dimension as a measure of accuracy. It was found that the wing technique (where resin wings are added to the denture and fit into corresponding grooves in the landing of the cast for purposes of accurate repositioning after removal of the impression material) was the most accurate and resulted in vertical changes between −0.06 and +0.08 mm. in 68 percent of the cases and between −0.13 and +0.15 mm. in 95 percent of the cases.



Home reliner materials sold over the counter have been condemned *(Woelfel and Kreider, 1968; Means, 1964; Winter, 1966)*; bone losses as great as 3–4 mm. have been reported in the anterior region and between 1 and 2 mm. in the posterior region. The continued application of home liners make the dentures too tight and malocclusion occurs accompanied by the loss of bone support.

**EFFECT ON THE SUPPORTING TISSUES.** This portion of the discussion will be divided into effects of dentures on the soft tissues and the effects on supporting bone. Although numerous articles have been written on the allergic response of the mucosa to denture base materials, the results of the study by Fisher *(1956)* are still valid. Although the oral mucosa may show an allergic response to the acrylic monomer, in only rare instances has it been established that the *polymer* produces an allergic response. The vast majority of cases showing irritation have been shown to result from ill-fitting dentures or from pressure sensitization. Love, Goska, and Mixson *(1967)* found that the fit of the denture had more influence on the condition of the supporting mucosa than any other factor. Their recommendation for the prevention of inflammation was to check dentures after six months of service. Other recommendations included removal of the denture at night, cleaning the dentures, and stimulating the supporting tissues by using a stiff brush. They consistently observed more problems with maxillary than with mandibular dentures. Lambson and Anderson *(1967)* recommend removing the maxillary denture several hours each day to avoid palatal papillary hyperplasia. A recent study *(Davilewicz, 1971)* showed that denture sore mouth caused by allergies was rare; when it was observed it occurred in patients with many sensitivities. It was suggested that resin components may be allergic, or they may elicit a response in combination with the oral flora, or they may form undetermined compounds during polymerization. Ill-fitting dentures have been blamed for malignant changes in soft tissues, but documented cases are extremely rare *(Mackenzie, 1970)*. A recent study by Heyden, *et al.* *(1971)* of the absorption of chlorohexidene by dentures, particularly self-curing dentures, resulted in the suggestion that the presence of absorbed chlorohexidene on the tissue-bearing surface of a denture may be a means of improving the conditions of the oral mucosa.

The effect of complete dentures on the mucosa in the region of the posterior palatal seal was studied by Ostlund *(1958)*. He measured the palative mucosa to be about 3 mm. thick. A slight thickening (2.77 mm. at 0 years to 3.25 mm. after 10–15 years) of the tissues after wearing dentures was observed but the difference was not statistically significant. The epithelium was usually 0.18 mm. thick which increased to 0.28 mm. if inflammation existed. He observed that within six months the epithelium in patients wearing complete dentures changed histologically, although the tissues had a normal clinical appearance. Kapur and Shklar *(1963)* studied the soft tissues at the crest of the ridge and found that patients developed well-formed stratum corneum with increased zones when compared to controls. In situations with well-adapted dentures, the stimulation caused more increased keratinization than tooth brushing. They also found a lack of inflammation in subjacent connective tissue indicating no irritation of the dentures. If keritinization is a mechanism to prevent trauma, then a well-adapted denture serves this purpose and stimulates the underlying mucosa. Von Scotter and Boucher *(1965)* measured the thickness of the stratum corneum and found the following values for natural, edentulous, acrylic denture, and Vulcanite: 14.3, 20.2, 17.8, and 5.8 μ. The natural teeth provide partial protection from mechanical stimulation and the acrylic dentures acted as stimulators. They found no correlation between thickness of the stratum corneum and the length of time the denture was worn, or the age of the patient. Parakeratosis was found to predominate in the stratum corneum under a Vulcanite denture.

The number of articles that discuss the loss of bone support in complete denture patients is extensive and this review will review only a selected few to illustrate the effect of denture base materials in this area. A recent literature review of alveolar bone loss under complete dentures was prepared by Kelsey *(1971)*. Tallgren *(1966)* reported a longitudinal roentgenographic-cephalometric study of subjects during long-term denture wear. She observed a marked reduction of morphological face height as a result of resorptive changes of the osseous alveolar process and a decrease of the rest face height. In another seven-year longitudinal study *(Tallgren, 1967)* she found, in complete denture wearers, a reduction in height of the mandibular process in the anterior region of 6.6 mm. or four times that of the maxillary process. A few years earlier, Wictorin *(1964)* studied the effect of the use of immediate dentures on the resorption of bone under maxillary dentures using a roentgenographic-photogrammetric method. He established that patients receiving the "conventional" denture treatment had significantly larger amounts of bone resorption than those receiving immediate denture treatment. It was proposed that the immediate denture provided protection against thermal and mechanical injuries during the healing process. It was also proposed that trauma, as a result of instability (due to incorrect occlusion and articulation), may cause bone loss. Carlsson, Bergman, and Hedegård *(1967)* and Carlsson and Persson *(1967)* measured changes in contour of the maxillary alveolar process under immediate dentures and morphologic changes of the mandible after extraction and wearing dentures. The greatest percentage change in bone support occurred in the first six months; continued changes took place for at least five years. Their studies suggest that later changes may be a result of loading conditions on the supporting structures.



## TISSUE CONDITIONERS AND SOFT LINERS

The use of soft liners on the tissue bearing surface of dentures has been of considerable controversy since their principal introduction around 1950. Since that time a number of reports have appeared which describe their properties *(Beall and Caul, 1946; Lammie and Storer, 1958; Travaglini, Gibbons and Craig, 1960; Craig and Gibbons, 1961; Eick, Craig and Peyton, 1962; A.D.A. Council on Dental Research, 1963; Wilson and Tomlin, 1969)*. The materials used for soft liners include velum rubber, vinyl and vinyl-acrylic polymers, acrylic polymers, and silicone elastomers. The vinyl and acrylic materials are made soft and flexible by the addition of oily or alcohol type plasticizers, or by copolymerizing with monomer units with sufficiently long side chains, such as butyl or actyl methacrylate. As expected, the former materials become harder as the plasticizers leach out in the oral fluids while the latter remains soft during clinical use. Care must be taken during processing so that good adhesion to the hard denture base results. Interest has been high in the silicone elastomers, but bonding to acrylic polymers (tensile bond strength ~ 150 psi), its low tear strength (~ 30 lbs./in.), and abrasion resistance, as well as the growth of Candida albicans in the liners have presented problems. Silicone liners have the best recovery from deformation (4 percent permanent deformation after 20 percent deformation for 24 hours). One statement which is not contested is that none of the current materials can be classified as a "permanent" liner even in the sense that a hard acrylic denture base is "permanent".

Tissue conditioners have been described by Braden *(1970a, 1970b)* as being composed of poly (ethyl methacrylate) and an aromatic ester- (often butyl phthalyl butyl glycolate) ethyl alcohol mixture. The materials form a gel and the ethyl alcohol has great affinity for the polymer. The optimum properties were obtained when as little alcohol as possible was used and a reasonable jelling rate was obtained to minimize distortion under dynamic conditions. At 37.4° C the materials functioned as viscous liquids with viscosities in the range of $10^6$ to $10^7$ poise. Fortunately, under the oscillating conditions of mastication, the elastic qualities of the gels predominated.

Gibbons *(1965)* reported the presence of Candida albicans in two-thirds of a group of fourteen patients wearing dentures with silicone linings. Five of the six cases showed no change, or white spots on the surface were negative for the Candida albicans. The white spots appear as tenaciously attached nodules which alters the suface contour of the liner and is usually associated with irritation of adjacent soft tissues. This observation has been confirmed by a number of authors *(Gruber, Lucatorto and Molnar, 1966; Bascom, 1966; Sauer, 1966; Woelfel and Paffenbarger, 1968)*. Gruber, Lucatorto, and Molnar *(1966)* conducted an *in vitro* study and found that sufficient amounts of zinc undecylenate eliminated the potential of the silicones to support the growth of these yeasts; 0.5 percent of zinc undecylenate was insufficient while 1.5 percent resulted in no growth.

Clinical studies of soft liners have been published *(Bascom, 1966; Sauer, 1966; Woelfel and Paffenbarger, 1968; Gonzalez and Laney, 1966; Means, Rupp and Paffenbarger, 1971)*. The clinical results for silicone liners were generally good, but in one study *(Sauer, 1966)* 50 percent of the cases were subject to the "white spot problem" which resulted in changes of the surface texture of the lining. Another study *(Woelfel and Paffenbarger, 1968)* showed that the molar-to-molar and flange-to-flange distances were not seriously changed during relining. The average dimensional change in the molar-to-molar region of thirteen maxillary dentures was 0.16 percent during rebasing and 0.11 percent during eighteen months of service; similar results were obtained for flange-to-flange changes. Changes in lower dentures were slightly greater; 0.33 percent in the molar-to-molar region and 0.20 percent in the flange-to-flange region. The liners were odorless, tasteless, pleasantly colored, and generally well tolerated by the tissues. Sore spots were found in areas of flexibility of the denture as a result of removal of the hard base to provide space for the liner. The aftertaste of tobacco and cleaning agents sometimes persisted and 85 percent of the liners showed "white spots" after eighteen months of service. Some bonding problems were observed and finishing was difficult, making adjustments a problem. Eight of thirteen patients, however, preferred the soft liner to the hard base. An additional clinical study compared Silastic 616 (oral cure liner) with Coe Super Soft (flexible acrylic liner) *(Means, Rupp and Paffenbarger, 1971)*. Six of the ten silicone liners showed no change in resilience and the other four became spongy. Four silicone liners became dark, presumably because of residual tin from the catalyst. Coe Super Soft liners did not deteriorate, but in several cases, resilience was lost and calculus-like deposits were difficult to remove from the surface. Cleaning the silicone liners with hypochlorite solutions was satisfactory but the Coe Super Soft liners were bleached by its use. The conclusion of all authors was that resilient liners should be considered to be temporary measures to be used in selected cases.

The clinical studies showed that breakage of lined dentures was a problem because of the thin layer of hard acrylic denture base. Morrow, *et al. (1968)* developed a method of strengthening the denture bases containing liners by incorporating a chromium-cobalt alloy framework in the hard acrylic.



A recent development in soft liners are the poly (ethyleneglycol methacrylates) *(Kliment, et al., 1968)*. When mixtures of diacetins are added during polymerization, the resulting gels have improved mechanical properties, reduced dimensional changes caused by swelling, and increased bond strength to poly (methyl methacrylates). This hydrophilic polymer has the interesting quality of being hard after processing and thus can be polished and finished by conventional means. However, it becomes flexible on storage in water or saliva. Two laboratory *(Clark, 1970; O'Brien, Hermann and Shepherd, 1972)* and two clinical studies *(Bell, 1970; Sklover and Tendler, 1967)* have been reported using resilient liners of this type. The material is available as a heat-curing gel, a self-curing powder-liquid type, and a heat-curing powder-liquid type. Generally, the latter form has been preferred. The heat-cured powder-liquid type has the following properties: the water sorption is 49 percent, the presence of oils results in a loss of weight of about 30 percent as a result of the loss of water, it has a tensile bond strength to acrylic of 70 $g./mm.^2$ with cohesive failure in the liner, an International Rubber Hardness of 32° (Knoop Hardness of about 2), strain in compression of 10 percent at a stress of 1000 $g./cm.^2$, and a percent set of 0.1 percent after 12 percent deformation for 30 seconds. The oxygenated denture cleaners were satisfactory but those containing oils should be avoided because of changes in hardness and color. The material does not encourage bacterial growth. One clinical study *(Bell, 1970)* involving seventy-three subjects showed that the retention was not significantly superior with the soft liner. The clinical advantages were that it remained resilient, bonded well to the hard acrylic base, and was easily adjusted and polished. No odors were observed with the lined dentures and there was no clinical evidence of fungi. The soft liner, however, was subject to staining and attack by some chemicals such as alcohol, had a low tear strength, and demonstrated that it may become impregnated with salivary calculus. These disadvantages can be minimized by proper use and care.

Two polymer-ceramic denture lining materials have been studied by Wright, Craigon, and Anderson *(1970)*. The soft polymer contained silane treated ceramics (silica and sodium fluorosilicate). The liners were stiffer in transverse deflection than Vivacryl but fractured earlier. One of the two products was more wettable by saliva and water than poly (methyl methacrylate) with contact angles of 51 and 67° compared with 97 and 78°. Both were rougher than acrylics after sandblasting and were less abrasion resistant.

Crum, Loiselle, and Rooney *(1971)* conducted a clinical study using completely resilient mandibular dentures, except for around the base of the teeth. A conventional and a resilient denture were constructed for each of thirty patients; twenty-six of the thirty patients preferred the resilient denture because of better retention and comfort, and the remaining four patients had no preference. The resilient dentures required 73 percent less adjustments as a result of inflammation. The resilient materials were not practical as a permanent denture because of inadequate physical properties.

## DENTURE ADHESIVES

Denture adhesives may consist of gum karaya, gelatin, pectin, sodium carboxymethyl cellulose, hydroxyethyl cellulose, and methyl cellulose *(Stafford, 1970)*, and the hydrolyzed neutralized calcium and sodium salt of polyvinyl methyl ether—maleic anhydride copolymer *(Swartz, Norman and Phillips, 1967)*. Antibacterial-antiseptic agents and wetting agents also have been added to denture adhesives. The retention of dentures using adhesives has been reported *(Kapur, 1967; Parker, 1968; Stafford, 1970)*. Kapur *(1967)* found adhesives increased the retention scores from 1.7 to about 2.7 for upper dentures on an arbitrary scale of 0–3 and from 0.7 to about 2 on lower dentures. No differences were observed between different brands of adhesives. However, the use of adhesives on twenty-four patients did not improve the masticatory ability of the denture patient and no correlation existed between denture retention and chewing performance. The lower dentures showed significant losses in retention after using adhesives in the chewing experiments. In addition, the adhesives did not significantly effect the taste discrimination for sweet and sour submodalities. Stafford and Russell *(1971)* found that patients could increase the force on old dentures from about 7 to 13 kg./cm.$^2$ with the application of adhesives, and from 12 to 18 kg./cm.$^2$ on new dentures. As observed by Kapur, the time taken to chew foods did not vary significantly regardless of whether adhesives were used or not.

Bartels *(1945)* reported that denture adhesives did not possess any inhibitory qualities toward microorganisms. Stafford and Russell demonstrated that denture adhesives (Co-re-go and Polygrip) supported the growth of Streptococcus mitis and Candida albicans but not Neisseria pharyngis. The growth of Candida albicans showed the presence of hyphae. The adhesives did not show any inhibitory effect on the oral flora. The length of time the adhesives remained between the denture and the tissue was measured by Swartz, *et al.* *(1967)* the loss was nearly linear for the first four hours, and at the end of six hours, the amount remaining for three products was 34, 42, and 60 percent respectively; the first two were Karya gum types and the third was the polyvinyl ether—maleic anhydride copolymer.



## SURFACE TREATMENT AND RETENTION OF DENTURES

The surface chemistry aspects of the retention of complete dentures has been studied by a number of investigators *(Craig, Berry and Peyton, 1960; Tyson, 1967; Brill, 1967; O'Brien, Craig and Peyton, 1968; Blahova and Neuman, 1971; Barbenel, 1971)*. The factors considered in the retention of dentures are: **a.** the capillary forces involving the liquid film between the oral tissues and the denture, **b.** the surface forces controlling the wetting of the plastic and the tissues by saliva, **c.** the seating force applied to the denture which to a considerable extent determines the thickness of the saliva film, **d.** the surface tension of the saliva, **e.** the viscosity of the saliva, **f.** the roughness of the surface of the denture, and **g.** the atmospheric pressure. The retention force, *F*, neglecting the viscosity term, can be expressed as

$$F = \frac{\gamma A (\cos \theta_1 + \cos \theta_2)}{dg}$$

where $\gamma$ is the surface tension, $A$ the area of the denture, $\theta_1$ and $\theta_2$ the contact angle of saliva against tissue and plastic, $d$ the film thickness and $g$ the gravitational constant. Thus increasing $\gamma$, $A$, cos $\theta_1$, and cos $\theta_2$ or decreasing $d$ will result in an increase in $F$. The effect of roughness is interesting since if $\theta_1$ and $\theta_2$ are less than 90°, increases in roughness will increase the ease of spreading of saliva and thus increase $F$; if $\theta_1$ and $\theta_2$ are greater than 90°, increases in roughness will decrease the spreading of saliva. Since the measured contact angles of saliva on acrylic are less than 90°, roughness has the former effect. Increases in viscosity of saliva will result in an increase in $F$ and if the viscosities of denture adhesives are used, they are sufficiently viscoelastic that the rate of removal of the denture must be considered. If denture adhesives are used, increasing the rate of removal will increase the observed value of $F$. One area of considerable confusion is the concept of reduced pressure in the saliva film as a result of the curvature of the meniscus. However, in liquids the presence of a reduced pressure in the film under static conditions is not possible because of the possible movement of the liquid. A more reasonable explanation is that the motion of the molecules to prevent a pressure differential results in an increase in the surface tension of the liquid in an isolated capillary space *(O'Brien and Yu, 1972)*. Evidence that the reduced pressure does not exist is that the force of separation of a spherical surface and a flat surface with a liquid bridge does not change as the atmospheric pressure is reduced from 742 to 100 mm. of Hg. Even under dynamic conditions the establishment of significant pressure differentials on each side of the meniscus is highly questionable.

The retention of dentures, of course, involves more than just the capillary effect. The muscles of the face can retain even a poorly fitting denture. Changes in the contour of the tissues with respect to the denture base can effect the film thickness and reduce the retention force, $F$. The thickness of the saliva film at the periphery is of great importance since it more nearly represents the $d$ in the equation and thus, if the soft tissue continues to maintain contact with the periphery of the denture, $d$ will be kept small, and retention will be maintained.

A considerable number of clinical studies *(Hermann and O'Brien, 1969; Skinner, Campbell and Chung, 1953; Tallgren, 1959; Boucher, et al., 1968; Battersby, Gehl and O'Brien, 1968; De Furio and Gehl, 1970; Blahova and Neumann, 1971; Gesser and Castaldi, 1971)* of the retention of dentures have been reported and a number of them have attempted to study the effects of the factors in the previous capillary equation. The retention of dentures is increased by the post-dam and peripheral seal, and decreased with a roofless denture *(Skinner, Campbell and Chung, 1953)*. These results would be expected because the post-dam and peripheral seal keep $d$ small, whereas the elimination of the palate would increase $d$ and decrease retention since one of the areas of poor fit has been in the palate. A longitudinal clinical study *(Tallgren, 1959)* showed that the retention with Vulcanite dentures after the first week was higher than acrylic dentures which is in agreement with the study of Anthony on the accuracy of Vulcanite dentures. However, over a period of eight years, the acrylic dentures had adequate retention. Maximum retention was observed during the first year, and after six years the mean retentive force was 250 g. These data would be anticipated since tissue changes would result in gradual decrease in fit; $d$ should increase and $F$ decrease.

Attempts to increase denture retention have included attempts to change the wetting properties of the denture. Three techniques have been (1) to produce a silica surface by the reaction of $SiCl_4$ to the surface layer of water on the denture, (2) to form a titanium dioxide surface using Fenton's reagent and an acid solution of $TiCl_3$ containing $H_2O_2$, and (3) to oxidize the surface of the denture by an electrical discharge in a vacuum. The $SiCl_4$ treatment resulted in ten of fifteen standard dentures and ten of fifteen physiologic dentures having an increase in retention of greater than 20 percent. These values are slightly higher than expected based on the capillary equation and the contact angles measured by O'Brien and Ryge *(1965)*. Vacuum electrical discharge reduced the contact angle of acrylic to about 15°, and the $H_2O_2 - Ti^{+3}$ treatment resulted in contact angles of 20 to 30°. Clinical measurements reported 40 to 70 percent improvement after vacuum discharge treatment, 30 to 70 percent for $SiCl_4$ treatment, and 20 to 24 percent decrease after $H_2O_2 - Ti^{+3}$ treatment. These data are from three clinical cases for each method. The values appear to be unusual and should be verified.

The use of a hydrophilic soft liner (poly hydroxy ethyl methacrylate) was investigated as a means of increasing denture retention *(Battersby, Gehl and O'Brien, 1968)* because the advancing and receding contact angles for water on the hydrophilic polymer were 0° compared with 75 and 54° respectively for conventional poly (methyl methacrylate). An *in vitro* test indicated that the force required to separate a glass plate and the hydrophilic polymer with a water film was 94 g./cm.$^2$ compared with 41 g./cm.$^2$ when poly (methyl methacrylate) was used. A clinical study of ten patients showed that eight of ten poorly fitting dentures lined with the hydrophilic soft liner increased the retention to the physiologic limit of 5.44 kg.; the remaining two dentures had a retention force of 3.68 and 4.37 kg. Later construction of a new hard acrylic denture for each patient resulted in maximum retention of 5.44 kg. Similar clinical results were obtained by Blahova and Neumann *(1971)*.



## TOOTH MATERIALS

As indicated earlier *(Myerson, 1957)*, designing dentures with a combination of porcelain and plastic teeth has been shown to have several advantages: **a.** occlusion is easy to establish by grinding mainly the plastic teeth, **b.** clicking as observed with only porcelain teeth is eliminated, **c.** fracture is minimized since the impact strength of the plastic teeth are higher than for porcelain teeth, and **d.** the masticating efficiency is maintained at a high level because the mechanical cutting edges of the porcelain teeth are not lost. Koran, Craig, and Tillitson *(1972)* measured the coefficient of friction of pairs of plastic and porcelain tooth materials and found that the value for porcelain on plastic, and plastic on porcelain in a wet environment was 0.30 to 0.32. The friction coefficient for plastic against plastic was 0.37 and porcelain against porcelain was 0.51. These data again indicate the advantages of using combinations of plastic and porcelain teeth. A clinical study by Franks *(1962)* of 140 patients over a period of five years showed that posterior occlusal wear caused loss of occlusion in centric, but the more satisfactory the dentures were from a clinical standpoint, the more wear occurred on the occlusal surfaces. The study suggested that wear resulted from food abrasion and not tooth contact. Thomson *(1965)* measured the attrition of acrylic teeth in a laboratory study. He showed a major decrease in the rate of wear as the contact area increased, but found little difference between brands of acrylic resin teeth. Tests run at 10–29 lbs. for about 300 hours (5/8 in. stroke at 60 times/min.) were comparable to clinical wear of a patient with a non-functional tooth-grinding habit. These loads are high compared to those used in chewing food (0.6–4.0 lbs.) and he suggested the type of wear studied may be higher than the tissues can tolerate comfortably. In a later study, Thomson *(1971)* showed large amounts of wear at 5 and 10 lbs. during the first day of testing, ~ 0.040 and 0.070 inches, respectively. The wear rate then decreased, and at twelve days the wear was 0.075 and 0.10 inches. When the load was increased to 20 lbs., the wear rate increased sharply.

Several investigations have been reported on the bonding of porcelain teeth to acrylic denture base materials *(Paffenbarger, Sweeney and Bowen, 1967; Semmelman and Kulp, 1968; Myerson, 1968)*. The use of a coupling agent, γ-methacryloxy propyltrimethoxysilane, to treat the surface of the porcelain resulted in a mean tensile bond strength for various teeth and denture base materials of 1,670 lbs./in.$^2$. It is claimed that the bond prevents seepage of fluids around the necks and ridge-lap portions of the teeth. The bonding places strains in porcelain teeth and fracture may result; the stronger the porcelain, the weaker the bond. If the surface of the tooth is ground, then the surface must be silane-treated again before processing. Room-temperature acrylics provide a better system with the silane treated teeth than with heat-cured denture base material but thermal cycling between 160 and 42° F drastically reduces the bond strength. It was found that the volume shrinkage on cooling was more important than polymerization shrinkage.

The bonding of plastic teeth to heat-cured denture base resins was reported in 1952 by Schoonover, *et al.*. More recently, Sørensen and Fjeldstad *(1961)* and Rupp, Bowen, and Paffenbarger *(1971)* reported on the bonding of plastic teeth to acrylic denture base materials. The measurements of tensile bond strengths showed that higher bond strengths were obtained with heat-curing than with self-curing resins *(Sørensen and Fjeldstad, 1961)*. The bond strengths of the former were usually equal to the tensile strength of the heat-cured denture base resins (370–570 kg./cm.$^2$), while for the latter, the bond strengths usually were 100–150 kg./cm.$^2$ less than the tensile strength of the self-curing resins (440–460 kg./cm.$^2$). Surface treatment of the teeth is critical and all wax must be removed and the tooth exposed to ethyl acetate or methyl methacrylate. The length of time the teeth should be exposed to the swelling effect of these two liquids depends on the degree of cross-linking of the ridge-lap surface of the tooth; the more highly cross-linked this area of the tooth, the longer the soaking and the weaker to tensile bond strength.

The bonding of self-curing acrylic denture base resins to plastic teeth has been improved by treating the teeth with a 50–50 mixture of dichloromethane and methyl methacrylate cold-curing liquid *(Rupp, Bowen and Paffenbarger, 1971)*. Using a four minute exposure of the plastic teeth to the liquid mixture, an average tensile bond strength of 431 kg./cm.$^2$ was obtained which was more than 80 percent of the tensile strength of the denture base resin. To avoid porosity, excess solvent-monomer must be sponged off before processing the acrylic base. Bond strengths were observed to increase up to seven minutes exposure but decreased as the time was increased further. The surfaces of the teeth must be wet during packing of the denture base resin but no excess should remain around the necks of the teeth. The results showed that the solution did not cause crazing or softening of the exposed surface of the plastic teeth.



This literature review will not include an indepth review of the effects of occlusal geometry (or the influence of the type of artificial tooth) on the supporting structures, but several articles deserve some mention. Mirza and Yurkstas *(1964)* discussed the influence of tooth materials on alveolar bone resorption. They claim that, from the results of a laboratory study, more force is transmitted to the denture base through a porcelain tooth than through a plastic tooth. Earlier Sharry, Askew, and Hoyer *(1960)* used a strain-sensitive lacquer to measure the deformation patterns of bones from dentures made for eighteen edentulous skulls. The results indicated that under identical loads, more deformation occurred in bone beneath dentures using anatomic forms than those using nonanatomic tooth forms. Deformation was observed in remote areas, heavy bone resisted deformation, and deformation was high at the foramina. The effect of occlusal geometry on chewing efficiency also has been studied *(Yurkstas, 1963; Sauser and Yurkstas, 1957)*. Chewing performance of five subjects was based on rankings of chewing tests on peanuts, carrots, and ham using eleven combinations of occlusal geometry. The carvings were scored 1 mm. in depth and width leaving sharp angular edges. They found that better performance was obtained when both the upper and lower occlusal surfaces were provided with cutting edges. The highest performance occurred when the cutting edges were in a mesiodistal direction on the upper occlusal surface. Even earlier, Trapozzano and Lazzari *(1952)* studied occlusal patterns with respect to efficiency and the effect on soft tissue ulceration. The denture base was kept the same and three types of teeth were mounted interchangeably on the base. Using two patients, they found that 20° teeth were more efficient than De Van teeth, which in turn were more efficient than Hall teeth. The greatest ulceration was produced by the Hall posterior teeth, less by De Van teeth, and the least by 20° teeth. They proposed that the ulceration may have been a function of the denture base deformation.

## DESIGN AND EXPERIMENTAL STRESS ANALYSIS OF DENTURES

**FORCES ON DENTURES.** Although researchers attempted to measure chewing forces as early as 1895 the significant articles in this area began to appear around 1950 *(Howell and Brudevold, 1950; Brudevold, 1951; Yurkstas and Curby, 1953)*. The average force on molars and bicuspids for 100 denture wearers (from 26 to 83 years of age) was 22–24 lbs., but the force on the incisors was only 9 lbs. It was observed that complete denture patients apply only 15 percent of the force applied by a person with normal dentition. The second premolar was found to usually carry most of the load during chewing, followed by the first molar and then the first premolar *(Howell and Brudevold, 1951)*. In a few instances (chewing raisins) the first premolar carried the most load. More recent studies found the distribution of force between the first bicuspid, second bicuspid, and first molar of a complete denture to be 16, 29, and 55 percent and the average force used to chew peanuts, coconut, or raisins was 1.5, 2.7, and 5.1 lbs., respectively. These low values reflect the low shear strength of these loads. The stress was calculated using 3.5, 6.5, and 14 mm.$^2$ for the respective contact area and the values were 1000, 270, and 240 lbs./in.$^2$ for the first bicuspid, second bicuspid, and first molar. More efficient chewing should be accomplished by using the first bicuspids where the stress is high.

The maximum force applied by patients on a single tooth in a complete denture was 26 lbs. However, the forces measured for chewing celery, carrot, apple, and meat were 19, 17, 14, and 10 lbs., respectively. Studies using mechanical models showed that 35 to 40 lbs. was required to "chew" meat. In actual chewing, however, only 10 lbs. may be needed since the lateral stroke of the mandible shears the meat. In general, raw vegetables required higher forces to reach the swallowing threshold than softer foods and complete denture wearers used an average of 80 strokes/min. on soft food and 65 strokes/min. on tougher food. The harder foods are generally chewed in the anterior region and the softer foods in the posterior area.

Atkinson and Shepherd *(1967)* studied the masticatory movements of the mandible and the forces developed during chewing. The position of the mandible and the force in premolar denture teeth were recorded simultaneously during the chewing of foods. They observed that significant forces were not developed until the teeth were nearly in contact; after contact the force increased without motion of the mandible. They did not observe significant sliding of occlusal surfaces over each other during chewing. During the initial reduction of food the force was larger on the working side and only near the end of chewing did the forces on the working and balancing side become equal and low in magnitude. Bearn *(1971)* measured the masticatory load carried by groups of posterior teeth during chewing of a biscuit. Three types of occlusal tables were used; broad, narrow, and knife. He found the average load for stroke was 4.2, 3.0, and 2.2 kg. for broad, narrow, and knife type occlusal tables, but no difference was found in the number of masticatory strokes to complete the chewing.

The relationship between the vertical dimension of occlusion and forces generated by mastication was reported by Tueller *(1969)*. He embedded strain gages in the palatal part of an upper denture and a central bearing point was attached to the lower baseplate; as the vertical dimension was gradually increased the biting power was reduced.



The forces on implant dentures has been compared to those on normal lower dentures *(De Hernandez and Bodine, 1970)*. They found the masticatory load with the implant dentures was 2–2.5 times more than with the conventional lower denture.

**DEFORMATION OF DENTURE BASES.** Regli and Kydd *(1953)* measured the deformation of acrylic and metal base dentures. The amount of deformation was measured by attaching strain gages to the lingual portion of a mandibular denture near the midline. They used one patient and one lower acrylic denture which was later modified to contain a metallic insert. When carrots were chewed there was an initial deformation toward the midline of 3.6 mm. which decreased as chewing continued to a value of 1.33 mm./chewing stroke. The average deformation away from the midline was 1.8 mm. When peanuts were chewed the deformation was 1.32 mm. toward, and 1.92 mm. away from the midline. When a metal insert was used the average deformation when chewing carrots and peanuts was 0.09 and 0.17 mm. toward, and 0.21 and 0.24 mm. away from the midline, respectively. It was concluded that the metal base denture was 8.5 times more resistant to deformation than the acrylic base and they proposed that the larger deformation of the acrylic base may contribute materially to atrophy of the residual ridge.

A later study by Regli and Gaskill *(1954)* measured the denture base deformation during function using a similar experimental arrangement as before *(Regli and Kydd, 1953)*. They measured the direction and magnitude of deformation during mastication and deglutition in three types of lower denture bases: (1) poly (methyl methacrylate), (2) poly (methyl methacrylate) with a gold insert, and (3) a metal base. Cusp teeth were used in the dentures and four patients were examined. During chewing, the plastic base dentures exhibited more deformation than the dentures with metal inserts or metal bases; reductions in deformation for the latter two varied from 50 to 70 percent. Reduction in deformation during deglutition was more variable with one patient showing no reduction and two patients showing reductions of ~ 50 percent for the metal base and ~ 70 percent for the dentures with metal inserts. During mastication, dentures with high ridges showed torsional deformation while flat ridge dentures exhibited compression. During deglutition, high ridge dentures showed extension and flat ridge dentures exhibited little extension.

The question of whether primary stress-bearing areas actually dissipate functional forces or are the forces transferred to other areas by the nonrigid acrylic denture base was examined by Lambrecht and Kydd *(1962)*. Strain gages were attached to the buccal and labial flanges and to the anterior and posterior palatal areas of five maxillary dentures. The subjects chewed peanuts and carrots; 30° teeth were used in all cases. Two types of deformation occurred: (1) extension or straightening of the base at the midline, and (2) compression or increase in the curvature of the base at the midline. The posterior teeth were set over the buccal slope of the ridge and functional forces caused rotation of the base about the crest of the ridge, thus, a flattening of the palatal contour. This flattening caused the base to move away from the tissue at the posterior palatal seal and a maximum movement of 1.5 mm. was observed. Also, the edges of the buccal flanges were forced into heavy contact with the tissues, thus deforming laterally, resulting in extension. When the patients chewed on the bicuspids the base was forced upward into the anterior portion of the palatal vault and compression resulted. When chewing occurred in the posterior areas, extension was observed in the anterior palatal region. However, the labial flange was primarily in compression although some torsional components were found. The authors postulated that the primary stress-bearing areas of a maxillary denture were on the medial slope and the crest of the residual ridge. A secondary stress-bearing area was the height of contour in the anterior palatal area. Based on these data, the authors suggested the following to minimize denture base deformation: **a.** provide minimal relief in the posterior palatal area and some relief in the anterior palatal area, and **b.** use cast metal bases.

Swoope and Kydd *(1966)* examined the effect of cusp form and area on the deformation of denture bases. In their study, the authors: **a.** compared the magnitude of deformation during masticatory and nonmasticatory tests, **b.** compared the duration of the deformation during swallowing and mastication, and **c.** evaluated the separate effects of cusp form and occlusal surface area on deformation. Tests were conducted using strain gages attached centrally to the lingual flange of mandibular dentures. Patients chewed carrots and peanuts. The teeth were of the 30° type which were later changed to simulate zero degree teeth by filling the fossae with self-curing acrylic resin and rounding the cusps. Then the buccal-lingual dimensions of the teeth were reduced by one-half. They found that wide zero degree teeth resulted in a significant decrease in compressive and extensive deformation compared to results with 30° teeth. The narrow zero degree teeth showed a decrease in deformation of the base when compared to the use of 30° teeth but did not vary greatly from the results with wide zero degree teeth. Deformation values for chewing varied from zero to 0.043 and zero to 0.010 inch for swallowing. Analysis of variance, however, showed no significant difference in deformation between the types of teeth or the occlusal surface area. Deformation was significantly higher during mastication compared with nonmasticatory functions, and chewing peanuts caused greater deformation than carrots. The mean duration of the deformation of the base during swallowing was 1,050 m. sec. and 290 m. sec. for masticatory strokes.



The nominal pressures on complete dentures were measured by Ohashi, Woelfel, and Paffenbarger *(1966)*. They found the projected area of twenty-one upper dentures were 22.8 to 36.6 cm.$^2$ and 14.5 to 24.4 cm.$^2$ for lower dentures. Forces during swallowing were found to be 1.5 to 15.8 kg. and thus the pressure exerted on the dentures was calculated to be 0.06 to 0.56 kg./cm.$^2$ for upper dentures, and 0.09 to 0.80 kg./cm.$^2$ for lower dentures.

One final article should be mentioned which relates to the deformation of denture bases. Koivuma *(1958)* concluded that dentures constructed of flexible materials differ greatly from a rigid structure in that the masticatory force is born by a limited part of the ridge close to the point of application of load. He claimed that the pressure, therefore, is not evenly distributed over all the tissues covered by the denture. Studies with nylon denture bases showed that if they were heavily deformed they did not completely recover.

**STRESS DISTRIBUTION IN DENTURE BASES AND SUPPORTING TISSUES.** A general article encouraging practitioners to consider the form and health of the soft tissues and residual ridges was published by Lytle *(1959)*. He encouraged the dentist to regularly determine the magnitude of the soft tissue displacement in order to provide a good fit for the denture base. Somewhat earlier, Stromberg *(1955)* reported preliminary measurements of forces of denture bases against supporting tissues but emphasized that no concrete conclusions could be drawn because of the extreme complexity of the problem. He compared the lateral pressure in the region of the buccal flange above the upper first molar with dentures constructed with zero degree and anatomic teeth.

Matthews and Wain *(1956)* used strain gages to examine dentures under load and found that the area of maximum tensile stress was on the polished palatal area. They also use a brittle lacquer method and observed no cracks on the labial aspect, but the cracks were confined to the palatal aspect indicating higher tensile stresses in this region. The palatal area just lingual to the incisors contained the maximum tensile stresses. They observed that when the denture was loaded unilaterally, cracks in the lacquer appeared on the side opposite to the loaded area. They recommended minimal incisal space and maximum permissible thickness of the base in the incisal palatal area to minimize these high stresses.

The stress distribution of upper dentures was reported by Johnson *(1965)*. He studied the effect of the thickness of denture bases and position of the teeth relative to the ridge on the stress distribution in the base. The dentures were loaded on acrylic casts which were covered with a 1.5 mm. thick layer of silicone rubber. Strain gages were attached in three positions along the midline, anterior, center, and posterior areas;

their orientation was established by brittle lacquer crack patterns. The denture was loaded vertically in 5 lb. increments to 60 lbs., and the strain recorded. The teeth were mounted either: **a.** on the ridge, **b.** 2 mm. outside the ridge, and **c.** 2 mm. inside the ridge. The same denture base was used, but the teeth were removed and remounted. He found that in the anterior region more strain resulted when anatomical teeth were used rather than cuspless teeth. Also, as the teeth were moved from inside to outside the ridge, the strain increased regardless of the thickness of the palate. When anatomical teeth were used, the strain increased when the palatal thickness was increased or decreased. With cuspless teeth, the strain increased with palatal thickness and decreased when the palate was thin.

Stromberg *(1955)* reported higher stresses in bases with anatomical than with flat teeth and found higher stresses on the balancing rather than the functional side of the denture base. Frechette *(1955)* showed higher stresses in bases with zero degree than with 30° teeth, which is in disagreement with the work of Johnson. Kubota *(1959)* used a two-dimensional photoelastic method and observed the compressive stresses in the portion of the base in contact with the mucous membrane and tensile stresses in other parts. He claimed that the wider the artificial teeth are separated from the interalveolar crest line, the greater the stress. Klötzer *(1964, 1966)* reported photoelastic studies which showed that slight changes in form, or the reinforcement of maxillary dentures resulted in marked changes in stress distribution. He found on the examination of lateral sections that the maxillary denture base functions as a transverse beam. Klötzer examined whole dentures photoelastically and reported areas of high stress concentration to be in the anterior palatal area.

Recently, Ledley *(1968)* published a theoretical analysis of the displacement and force distribution of the tissue-bearing surface of dentures. The treatment is based on the situation that during chewing, dentures are displaced by compressing the supporting soft tissue which produce a reactive force on the tissue-bearing surface of the denture. The experimental quantity needed is the viscoelastic properties of the oral mucosa.

The stress distribution on maxillary dentures was examined in centric, function, and protrusive loading by Craig, Farah, and El-Tahawi *(1971)*, using a three-dimensional photoelastic method. Loading was carried out on a Hanau articulator, the dentures stress-frozen, and then transverse sections 0.1 inch cut from the denture. In general, higher stresses were observed in areas under the teeth toward the midline of the base but the midline area had low stresses. The stresses were compressive and only one section of the six dentures tested showed any tensile stress in the midline area. For the dentures loaded in centric, the stress increased from zero at the central incisors to a maximum at the mesial portion of the second premolar and then decreased to zero just distal to the second molar. Higher compressive stresses were observed at the ridge areas than the midline for most sections. The ridge areas having the highest stresses were from the cuspid to the mesial of the first molars. In the previous tests the condyles of the articulator were retained; when the condyles were effectively removed, free-end loading resulted in somewhat different findings. Again, the ridge areas had higher stresses than the midline but two maxima in the ridge area were observed, one in the first premolar region and a second in the second molar region with a minimum in the region between the second premolar and the first molar. A further test using maxillary dentures with anterior undercuts showed higher stresses in the anterior region both in the ridge and midline areas. The stress at the midline was at maximum in the central incisor section and decreased gradually for more posterior sections. The maximum stress in the ridge areas was in the first premolar section. When the maxillary denture was loaded in lateral functional position, the stresses were compressive and the stresses at the ridge area were higher on the balancing side than on the functional side. The stresses on the functional ridge and the midline were comparable, being high in the anterior sections and decreasing in posterior sections. The stress on the balancing ridge was high between the first premolar and distal of the second premolar with the maximum being in the area mesial to the second premolar; this sharp increase is believed to have resulted from bending of the base from single contacts of the lingual cusps of the upper and the buccal cusps of the lower teeth on the balancing side, while the functional side had buccal-to-buccal and lingual-to-lingual cusp contacts. When the maxillary dentures were loaded in protrusive, higher stresses were observed at the midline in the central incisor region. For more posterior sections the stress at the midline and ridge areas were not significantly different. Again, the stresses were compressive on the tissue-bearing surfaces of the denture base and were low in the posterior sections.



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# SECTION REPORT

## PROPERTIES OF DENTURE BASE MATERIALS

**HARD PLASTIC BASE MATERIALS.** A review of the pertinent available literature concerning the mechanical properties of denture base materials reveals that certain properties are more significant than others. Current denture base resins can be described as relatively soft (Knoop hardness about 20) and an increase in hardness would seem desirable. Denture plastics are rather flexible and moderately strong (elastic modulus of 300,000 to 500,000 psi, compressive strength of 20,000 psi and tensile strength of 10,000 psi). Compressive strength is not considered to be a critical factor in clinical use. Impact and fatigue strengths are the most important mechanical properties for consideration; fatigue strength for *in vivo* function and impact strength to prevent accidental fracture outside the oral cavity.

According to reported data and estimates, intraoral fracture of acrylic resin denture bases occurs in 3 to 10 percent of those studies, and these fractures usually occur as a result of fatigue failure. Ideally, impact strength should be similar to that of the polycarbonates, but more realistically in a range between polycarbonates and modified vinyl polymers. Fatigue strength should be increased above the current level of poly (methyl methacrylates). A lower thermal expansion would also be more desirable.

It was the consensus that more information is needed on the incidence of fractures *in vivo* and the conditions under which fracture occurs: **a.** for maxillary and mandibular incidence, **b.** for different material systems involved, and **c.** for different types of occlusal concepts.

**SOFT BASE MATERIALS.** Soft denture base and lining materials are widely used. They have been used to accommodate individual patient variations in morphology, physiology, and psychologic response to conventional hard acrylic resin bases. Even though controlled experimental evidence of the successful application of soft materials is sparse, patient reaction, and clinical response seem to indicate empirically that the use of soft base materials, particularly where supported by hard resin, do relieve local stress concentrations providing an added measure of patient comfort.

More extensive use of soft materials is currently precluded by lack of a suitable product. Numerous substances have been advocated; among these are natural rubber, polyvinyl acetate-polyvinyl chloride co-polymers, plasticized PVC, methyl methacrylate co-polymers, and silicones. The ideal material should contribute to the preservation of the tissue support which remains, rather then compensate for anticipated change. Laboratory and clinical studies have established that a variety of materials are available with a range of elastic and viscoelastic properties, but that none of the current materials can be classified as permanent.

The critical qualities or properties of soft base materials are as follows:

1. Shore A Durometer hardness of approximately 40 (comparable to Silastic 390), and no change in hardness with service
2. Good bonding to the parent base
3. Total recovery from deformation
4. Easily adjusted
5. No support of bacteria or fungal growth
6. Simple processing technique which can be performed with the parent base
7. Color stable, odorless, and tasteless
8. Dimensional stability and accuracy
9. Minimal absorption of fluids
10. Does not deteriorate, weaken, or distort the parent base
11. Nonirritating and nontoxic
12. Good surface wettability
13. Adequate mechanical strength
14. Easily cleansed

It was concluded that the first priority in the further improvement of soft liners should be directed toward the development of a liner processed in the laboratory with the aforementioned qualities. Additional desirable properties for a soft material to be used as a direct liner include a viscosity similar to light-bodied mercaptan or silicone rubber, and bonding capability to a previously processed base.

There is little documented evidence to show the effect of soft liners on occlusion, masticatory efficiency, or loss of supporting structures. However, response from difficult denture patients seems to indicate that masticatory efficiency is improved with the use of a soft liner. When soft materials are used as a direct liner, changes are precipitated which require occlusal adjustment.

When placed under occlusal load, available soft liners are essentially noncompressible. It would be more appropriate if these materials simulated the oral mucosa in that the ease of deformation should be the same as, or greater than, normal soft tissue. The suggestion was made that a soft liner be developed incorporating the concept of a foam substructure with a skin layer permitting alteration and repair.



## TISSUE CONDITIONERS

In recent years, soft materials have been developed for use as conditioning agents within the hard denture base and as functional impression materials. The consensus suggests that insufficient attention is given to the selection and application of the proper material for the given clinical task. For example, a material may exhibit high flow over a short period of time, compared to another similar material which may have lower initial flow, but remain active over a longer time interval. Despite the apparent clinical and laboratory abuse of the available tissue conditioners, their effectiveness is demonstrated by improved patient comfort and denture stability.

## METAL BASES

In the past, cast metal bases have been used to minimize denture breakage, improve accuracy, improve denture hygiene, increase thermal transfer, and decrease base deformation. It has been demonstrated that, as commonly produced, metal bases are not more accurate than those fabricated from acrylic resins. However, certain metals can be cast that would produce a base more accurate than acrylic resin. Even though there may be significant differences in the accuracy of properly produced metal and acrylic resin bases, the elastic modulus may be sufficiently higher for the metal base to provide a better distribution of occlusal stress.

## COMPOSITE BASES

Optimal base systems could be layered or fiber-reinforced. There is clinical evidence to suggest that the incorporation of artificial teeth directly in an elastomer is undesirable because of reduced masticatory efficiency. However, better control of tooth movement within the elastomer would make the system more desirable and should be investigated further. Combinations of metals and soft materials could be used to produce a desirable denture base.

## SURFACE EFFECTS

The use of silane coupling agents on porcelain teeth has resulted in bond strengths of 1,700 lbs./in.$^2$ between porcelain teeth and denture base plastics. Fracture, particularly around posterior teeth, and the necessity of applying the coupling agent in the laboratory, have slowed the acceptance of this surface treatment. The fractures may result from the mismatch in the thermal coefficient of expansion of porcelain and plastic, or from the mechanical retention areas in porcelain teeth since little fracture was observed with treated anterior teeth. One attempt to resolve the problem has been for the manufacturers to bond a polymer to the silane treated ridge-lap surface of a porcelain tooth which in turn is bonded to the denture base during processing. The process is expensive and thus not too attractive. The bonding of porcelain teeth to a denture base prevents spaces around the teeth which contribute to odors and present cleaning problems. The bonding of porcelain teeth and plastic bases increases the opportunity of using short posterior teeth when space is limited.

Bonding of plastic teeth to heat-curing acrylics is not a problem, nor is the bonding of plastic teeth to chemically activated acrylic plastics providing the teeth are soaked in methylene dichloride before processing.

Increasing the wettability of denture plastics and teeth by saliva has been accomplished by surface treatments with materials, such as $SiCl_4$, which react with surface water to form a silica-like surface. The retention force, measured on a model system in the laboratory, was increased 10 percent by the silane treatment. A double-blind clinical study showed that 90 percent of dentures treated with silane could be identified based on cleanliness, presence of stain, and patient response. Another clinical study on well-fitting new maxillary dentures showed that the evaluation of a possible increase in retention using silane treatment was not possible because the pain threhold of the patient was reached before the release of treated or untreated dentures. It should be emphasized that silane treatment does not improve the retention of poorly fitting dentures.

The consensus was that wettability of denture bases was an important factor in denture retention, but it was not possible to numerically identify percentage of its contribution to overall retention.

A number of models have been developed to study wetting and adhesion between dissimilar surfaces. Theories have been developed and proven which relate retention with isolated capillary spaces, similar to that between the denture and tissue. It has been shown that retention is related to vacancies in the liquid films which result in higher than normal surface tension at the liquid meniscus; thus, retention of dentures in a static condition is not related to vacuum. In a dynamic or loaded condition, the reduced pressure in the film is balanced by an increase in the surface tension at the meniscus. It was proposed that studies should be made to determine the magnitude of the effect of capillary forces on clinical retention of dentures.

The development of a cement which would adhere the trial or final denture base to the tissue was proposed. The material may need to be adhesive for only a few hours to one week and could eliminate the need for a palate in a maxillary denture. The adhesive could be a pressure—sensitive type and biodegradable to allow easy removal. Its net effect could be an improvement in masticatory efficiency through more effective use of the occlusal scheme provided.



## DIMENSIONAL CHANGES

When used according to manufacturer's directions, the accuracy of available impression and die materials is such that it does not significantly affect the accuracy of the processed base. A variable predetermined control of the setting time of impression materials would be desirable since the loaded tray could be placed, patient response (if desired) completed, and the setting reaction activated at the appropriate time as determined by the operator.

Clinical evidence shows that the use of a silicone putty plus a silicone-corrected impression should not be advocated for complete denture impressions because of deformation of the tissues.

The movement of posterior teeth during processing of acrylic resin dentures and operator clinical error are sufficiently large to require occlusal adjustment prior to insertion of the prostheses for patient service. Based on experimental evidence and clinical observation, consensus suggests that processing changes frequently cause an increase in the vertical dimension of occlusion at the biscuspid-first molar region in the range of 0.0 to 2.0 mm. This change is due primarily to the force generated during flask closures and may be a function of such factors or shape of the cast, thickness of acrylic resin, tooth form, and flasking media among others.

Many patients cannot identify errors of significant magnitude (i.e., more than current materials impose). However, it is desirable that a theoretically accurate and stable base be used to protect the supporting structures. There is minimal dimensional change of the denture base during patient service as compared to changes occurring in tissue support.

Repair of defective acrylic resin bases with self-polymerizing poly (methyl methacrylate) can be made without significant distortion.

## CLEANING OF DENTURES

**HARD MATERIALS.** The accumulation of debris attached to the denture base in service generally consists of mucin, plaque, and calculus. These substances adversely affect the tissue health and should be eliminated. Currently, denture prostheses are cleansed mechanically by brush or vibrating instrument, as well as soaking in a chemical solution. Available experimental evidence suggests that there is no difference in the effectiveness of soaking and vibrating media. Regardless of the cleansing modality, brushing seems necessary to remove the gross debris. However, brushing of hard and soft base materials may result in surface abrasion and wear, with or without a cleaning agent. Further investigation of industrial techniques for cleaning was suggested.

A completely satisfactory soaking cleanser is currently unavailable. Certain substances with relatively high pH have been shown to attack porcelain teeth with resultant deterioration which adversely affects the response to occlusal stress. A suggested Calgon-hypochlorite solution has proven effective for cleaning acrylic resin bases. However, this medium is detrimental to the integrity of chromium-cobalt alloys, silicone base materials, and the pins used for mechanical retention of anterior porcelain teeth. The inclusions of disclosing stains in cleansers to assist patient care of dentures may be contraindicated since it migrates into areas around the teeth from which it cannot be removed.

Bacterial penetration of acrylic resin bases has not been conclusively demonstrated. However, odors emanating from the cut surfaces of dentures previously in use have been observed and suggest penetration of some organisms or substances. Experimentally incorporated materials in denture bases to discourage such activity has been discontinued since it disrupts the distribution of normal oral flora. Other procedures used to enhance base surface wettability have reduced the ability of some substances to adhere, but the reported effectiveness is limited.

**SOFT MATERIALS.** Problems in cleaning soft base materials are similar to those encountered with hard materials but with a greater degree of difficulty. One factor particularly related to the use of silicone base materials involves the growth of microbial organisms on and in the material. *In vitro* evidence supporting the claim that silicones enhance fungal growth by supplying nutrients is controversial. The techniques currently available for controlling the presence of microorganisms on or in silicones seem to include improved hygiene by brushing three times daily with mild soap, or the use of Zephiran chloride solution in 1:750 concentration for a fifteen minute daily soaking after brushing with water. The latter was found to be the most effective.

## ABRASION AND WEAR.

Generally, appreciable wear of artificial teeth in function is not desirable. There is no significant documented evidence of correlation between loss of vertical dimension of occlusion and occlusal wear. Consensus suggests that complete denture to complete denture occlusion with acrylic



resin or porcelain teeth does not present the problem that is involved with dissimilar conditions; for example, the articulation of natural or restored natural teeth or artificial teeth with metallic onlays, with acrylic resin or porcelain teeth.

Factors involved in artificial tooth wear include design of the denture and its fit, tooth design and material, vertical dimension of occlusion, and the morphology and physiology of the supporting structures. Wear of artificial teeth is less than changes observed in the supporting structures of the denture prosthesis. Unresolved is the question: *does tooth wear result in less loss of tissue support or encourage deterioration of the basal tissues?*

It is recommended that a plastic posterior tooth be developed with increased abrasion resistance and with the same elastic and viscoelastic properties of currently available acrylic resin teeth.

## STRESS DISTRIBUTION

Few attempts have been made to study the effect of the material, shape of the teeth, and supporting structures on the stress distribution within the denture and supporting tissues. Considerable difference of opinion exists in the literature suggesting the need for more clinical and laboratory studies. A practical laboratory photoelastic model system has been developed to permit the study of stress distribution in the denture base and teeth as a function of selected variables. A clinical protocol has likewise been developed to study the masticatory efficiency of dentures designed to include variable occlusal schemes.

Several suggestions for improving the masticatory efficiency of prosthetic occlusal schemes were suggested: **a.** stabilization of the denture base on supporting tissues with a biodegradable adhesive to make the existing occlusion more effective, **b.** provide an occlusal design for posterior teeth incorporating multiple point contacts with adequate egress, **c.** increase use of tooth-supported complete dentures, and **d.** investigation of the implant concept to distribute occlusal stresses directly to the bony support while by-passing the soft tissues.

## NEW MATERIALS

In view of the incidence of accidental injury, it is desirable to have available a radiopaque resin material. Current studies indicate that opacifying additives must be in such large quantities that they adversely affect the physical properties of resin tooth and base materials. Further approaches to the solution of this problem are urged.

The literature documents unfavorable experience with the "pour" technique for processing denture resins with respect to changes in occlusion. However, many of the causes of these problems have been resolved and it is recommended that the technique receive further study and investigation. It is also recommended that the "pour" technique be considered for the production of a duplicate denture for diagnostic purposes.

In the consideration of new base polymers, attention should be directed toward selecting those with increased thermal conductivity, strength, and stiffness.

Respectfully submitted,

Robert G. Craig, *Chairman and Reviewer*
William R. Laney, *Secretary*
M. Kamal El-Ebrashi, *Reviewer*
Kamal Asgar
Gerhard M. Brauer
John F. Glenn
John B. Heyde
Jean-Noel Nally
William J. O'Brien
Kenneth D. Rudd
Gunnar Ryge
Dennis C. Smith
Duane F. Taylor
Julian B. Woelfel
Edward J. Plekavich, *Section Assistant*

# DISCUSSION OF REPORT

Following the reading of the Section's report by Craig, Rudd made the motion for acceptance. Laney seconded the motion which was passed.

## RE: METAL BASES

Boos objected to the statement, "metal bases are not more accurate than those fabricated from acrylic resins." He felt that metal bases properly processed *were* more accurate. Craig agreed that certain metals can be cast that produce a base more accurate than acrylic resin as stated further on in the paragraph within the report. Boos felt that the paragraph contains conflicting statements.

## RE: RETENTION AND SURFACE CEMENT

Boos commented that a surface cement which would eliminate the need for a palate in a maxillary denture indicated a roofless denture. He felt that from previous experience, this reduction of coverage over a stress-bearing area (the palate) is unsatisfactory. Woelfel replied that if such a cement could be developed, the palatal coverage could be eliminated because of the advantages of thermal conductivity, tissue stimulation, and the equalization of pressure exerted on the upper and lower arches, which probably would eliminate many lower denture problems. Boos reiterated his point that experience with roofless dentures has shown that the maxillary residual ridges recede, leaving a large palatal area which could have been used as a good stress-bearing area.

Lytle questioned the Section members regarding the statement, "The material may need to be adhesive for only a few hours to one week and could eliminate the need for a palate in a maxillary denture." Lytle asked if this inferred that the patient would leave the denture in for one week. Craig responded that the members thought that certain materials, such as the cyano acrylates, may be sufficiently biodegradable to offer this opportunity in the future.

Laney commented further that such a system would be a closed one, so that other materials would be unable to get under the denture while that cement was in place.

Ramfjord stated that the mucosal cells are renewed within one week and that some provision must be made for the escape of the dead cells, making the proposed adhesive system impractical.

## RE: CLEANSING OF DENTURES

Boos commented that the cleansing effect of a Calgon-hypochlorite solution was quite satisfactory when properly controlled as to time and concentration for both acrylic resin and chrome-cobalt appliances. Craig replied that the solutions were strongly recommended for acrylics, but soaking in such solutions, which was unfortunately the recommended procedure, would seriously effect chromium bases.

SECTION VI

# Post-Insertion Changes in Relation to Complete Denture Occlusion

# REVIEW OF LITERATURE

## Changes in the Supporting Structures as a Result of Wearing Complete Dentures

*JAMES T. JACKSON*

Several authors have reported changes in the oral mucosa *(Lytle, 1957, 1959, 1962; and Chase, 1961)*, muscles of mastication *(Boos, 1959)*, and the temporomandibular joints *(Block, 1951; Jankelson, 1962; Kraus, 1963; and Vinton, 1964)*, of edentulous patients wearing complete dentures. Those changes that are destructive have been attributed to both mechanical and biological causes. Oral tissues are movable and displaceable, and the amount of tissue displacement varies with the individual tolerance of the tissues and the factors causing the displacement *(Boos, 1959)*.

### ORAL MUCOSA

**NORMAL MUCOSA OF THE ORAL CAVITY.** Neufeld *(1958)* wrote, "it is apparent that a well keratinized epithelium firmly attached to the basal bone can withstand considerable occlusal loads as transmitted by a denture base, while a poorly keratinized mucosa firmly attached to the basal bone is readily injured, when subjected to occlusal trauma." "The patient who is in good health, both physically and emotionally, is generally predisposed to successful denture treatment." If impressions are made of deformed tissues, the new dentures will continue to deform the tissues, and the patient's condition will not be corrected *(von Krammer, 1971)*.

**TISSUE DISPLACEMENT BENEATH COMPLETE DENTURES.** According to Lytle *(1957)*, mechanical abuse of the soft tissues beneath complete dentures may vary from slight displacement to gross deformation.The soft tissues beneath these ill-fitting dentures are trapped between the denture base and the underlying bone. If the soft tissues beneath the denture bases are displaced within normal physiologic limits, they will return to their resting form. When these same soft tissues are subjected to excessive stress, they are deformed and lose their resilient quality. Lytle *(1957)* felt that these conditions must be corrected before new dentures are constructed. Denture retention may overcome the gross occlusal discrepancies but this is generally at the expense of the health of the soft tissues. The changes in the form of the soft tissues effects both the impressions for new dentures and jaw registrations *(Lytle, 1957)*. The destruction of residual ridges was evidenced by areas of localized inflammation of the soft tissues where there had been excessive pressure from the ill-fitting dentures *(Lytle, 1959)*. Healthy mucous membrane is a light pink, translucent, moist, and varies in thickness *(Neufeld, 1958)*. Ill-fitting dentures cause inflammation, ulceration, hypertrophy, hyperplasia, and other disturbances of the tissue. The lesions created bleed freely and are quite often very painful. These changes in the mucosa cause the denture to lose retention, create occlusal imbalance, and decrease efficiency resulting in tissue destruction, all of which produces a recycling of the existing problem *(Neufeld, 1958)*. The patient's general health and nutritional status may also be predisposing and/or causative factors. Neufeld *(1958)* suggested that the changes observed in the mucosa are caused by the unequal distribution of functional forces, and that balanced occlusal harmony was needed as a stimulus for the tissue to remain within physiologic limits.

**CONCEPT OF ORAL MUCOSA CONDITIONING.** For years, dentists have advised patients with sore mouths to leave their dentures out until the tissues have recovered to a normal condition *(Lytle, 1957, 1959, 1962; Chase, 1961)*. Schultz *(1951)* relined the dentures with wax and allowed the patient to wear the prosthesis a few hours before rebasing. Chase *(1961)* reported that hypertrophic tissue was reduced by having patients chew an inflated plastic bag as a method of tissue conditioning.

Lytle *(1957, 1959, and 1962)*, Boos *(1959)*, and Wilson, Tomlin, and Osborne *(1966)* realized the importance of conditioning soft tissues prior to prosthetic treatment. They suggested that old dentures should not be worn for a period of time before impressions are taken permitting the deformed and traumatized soft tissues to recover. Most patients will not go without their old dentures, therefore, a soft material must be used as a reline to permit tissue recovery.

Chase *(1961)* relined 343 dentures with a tissue conditioner and evaluated the changes after treatment by: **a.** observation of casts before and after three days of treatment, and **b.** checking the fit of baseplates on a cast prior to conditioning, and an absence of fit after ten days treatment. He felt this represented tissue recovery, that is, a return to a more normal contour.



Klein and Miglino *(1966)* treated eighty-five patients and found a generalized improvement in the health of denture bearing tissues after tissue conditioning. Their opinion was based on clinical observations of the return of normal tissue color and patient comfort.

**TIME NECESSARY FOR RECOVERY.** Generally, the ridges of the young, healthy individuals will recover in forty-eight to seventy-two hours *(Lytle, 1959, 1962; and Dukes, 1965)*. By means of intraoral roentgenograms of soft tissues taken before the removal of ill-fitting dentures, and after a seventy-two hour period of tissue rest, Dukes *(1965)* found that the thickness of the soft tissue increased in all fourteen subjects.

According to Lytle *(1959)*, tissue recovery can be observed if the ill-fitting dentures are removed and the tissue left at rest for a period of forty-eight to seventy-two hours. Recovery with tissue conditioners was also recognized by Bruce *(1963)*, Chase *(1961)*, and Klein and Miglino *(1966)*. The time span for tissue recovery was generally longer with tissue conditioners when compared to complete tissue rest. Chase *(1961)* reported tissue recovery, or a return to a more normal contour, after ten days of treatment. In a similar clinical study, Klein and Miglino *(1966)* also noted from clinical observations that tissue color and patient comfort improved with tissue conditioning.

**TREATMENT PLAN.** The following treatment plan was recommended by Lytle *(1957, 1959, and 1962)* when the soft tissues were grossly deformed and traumatized, and the patient was unable to be without the denture for the time required for tissue recovery.

1. Correct the occlusion and other denture defects causing instability and trauma.
2. Correct the impression surface of the denture by locating and relieving all areas causing excessive pressure and deformation.
3. Place a temporary reline material in the dentures after they have been left out overnight. This will improve stability and help control soft tissue form. It is necessary to remove the relining material and repeat the procedure every few days.
4. Minimizing or eliminate stresses by employing a soft diet. Remove the dentures at night.
5. Instruct the patient to stimulate the soft tissues by massage.
6. Leave the dentures out of the mouth forty-eight to seventy-two hours prior to making an impression.

These six steps will help bring abused soft tissues of the denture supporting area back to health and a more normal form *(Lytle, 1957, 1959, and 1962)*.

## MUSCLES OF MASTICATION AND THE TEMPOROMANDIBULAR JOINTS

One cannot consider muscles without joints, or joints without muscles, as they are interrelated and interdependent structures *(Jankelson, 1962)*. The musculature and the temporomandibular joints, as well as masticatory functions, are altered by malfunction. To proceed with the technical steps of prosthetic reconstruction without first correcting the abnormal conditions may extend malfunction into the service and result in a limited use or failure of the restorations *(Boos, 1959)*. Boos *(1959)* reported that the musculature was a predominant factor in mandibular position, esthetics, and masticatory efficiency. Mandibular position determined the relation of the condyles in the glenoid fossae. When the musculature was normal, and the occlusion was in harmony with the movements of the mandible, the temporomandibular joints functioned normally.

Martone *(1962)* found that the clinical analysis of muscular activity indicated an association between the type of stimulus and the sequence of events which followed. If the stimulus was a bolus of food entering the mouth, the muscles of mastication, accompanied by various lip, cheek, and tongue activities assisted in the masticating process.

**MUSCLE TONICITY AND THE PLACEMENT OF TEETH IN COMPLETE DENTURES.** Heartwell *(1968)* pointed out that faulty tooth position or a poorly contoured denture base destroyed the normal tonicity of the muscles. Lack of support allowed sagging, and stretching retarded the normal contracture of the muscles with loss of tonus. If the muscles of facial expression were not properly supported, either by the natural teeth or by the artificial substitutes, the facial expression did not appear normal.

Martone *(1962)* wrote "that if the teeth are placed too far labially, the orbicularis oris is stretched and the modioli are positioned too far anteriorly, and prevent proper functioning. The stretching of the lips against the teeth also tend to exert a dislodging force on the maxillary denture."

**MUSCLE TONE AND GERIATRIC CONSIDERATIONS IN COMPLETE DENTURE PROSTHODONTICS.** A study by Vinton *(1964)* showed that the loss of tissue elasticity in geriatric patients commonly exceeded 90 percent and resulted from the degeneration of the muscle fibers and their substitution by connective tissue. Associated with the atrophy of the muscle fibers was an atrophy of the cells of the mucosa which covered the muscle. In addition, the capacity for repair through cell division and tissue oxidation was impaired. The increased pain threshold and the reduction in muscular capacity explained the magnitude of masticatory force reduction, from an average of over 150 pounds per square inch in the young adult, to an average of 25 pounds per square inch or less in elderly patients.



Boos *(1959)* found that physiologic rest position was the neutral center of the elevator and depressor muscles which were in a tonic contraction and represented the unstrained condyle position in the glenoid fossa. Rest position and maximum biting force are located at the same vertical dimension *(Boos, 1959)*. Tensions and habits when present may cause changes in the rest vertical relation.

Heartwell *(1968)* wrote that "when a muscle length is shortened, as in the establishing of excessive interocclusal distance, the fibers of the elevator muscles shorten and the new muscle lengths become equal to the maximum length of the lever system itself, thus reestablishing optimum force of contraction by a muscle. Constant overstretching of the depressor muscles make their normal contraction impossible and cause these muscles to lose power and to weaken. Heartwell *(1968)* also feels that when excessive interocclusal distance is established with dentures, the lessened force extends to the residual ridge and is short-lived, and the depressor muscles are weakened. With muscles at rest, a certain amount of tonus usually remains. This residual degree of contraction in skeletal muscle is called *muscle tone*. The blocking of muscle spindle impulses causes loss of muscle tone, and the muscle becomes almost flaccid. Kraus *(1963)* stated that "violent tensing of a muscle due to intrinsic or extrinsic irritation causes muscle spasm."

**DIET AND MUSCLE TONICITY.** Heartwell *(1968)* wrote that "the lack of protein in the diet of the geriatric individual accounts for the loss of skeletal tone and this loss of tone is reflected in the muscles of mastication. Registration of jaw relations for these individuals is difficult to accomplish and repeat." The treatment of muscle spasm by the use of ethyl chloride spray and gentle limbering movements have been found quite simple and is a most effective procedure *(Kraus, 1935, 1941, and 1963)*.

**MUSCLE THERAPY.** The conditioning treatment for muscles involves the application of physical muscular therapy, directed particularly to the muscles of mastication. An exercise based on the stretch-relax theory reported by Boos *(1959)* stated that every patient requires conditioning of the musculature and supporting tissue, even if all conditions appear to be normal. The patient should be put on the relaxation exercise for a minimum of one week to ten days before jaw relations are registered. The longer the time, the better the advantage in obtaining and facilitating normal registrations.

**SYMPTOMS OF TEMPOROMANDIBULAR DISTURBANCE.** According to Jankelson *(1962)*, symptoms commonly regarded as indicating temporomandibular disturbances include pain, whether during opening, closing, resting, or applying pressure; restriction of opening movement; deviation of the mandible during opening and closing; crepitus, and clicking or snapping.

**CAUSES OF TEMPOROMANDIBULAR JOINT DISTURBANCES ASSOCIATED WITH COMPLETE DENTURES.** Vinton *(1964)* found that loss of intermaxillary space, especially in the posterior segment, resulted in temporomandibular joint pain.

Kraus *(1963)* felt that muscle tension was probably the most frequent contributing cause of muscular derangement of the temporomandibular joint. He further stated "that if the muscles involved with the temporomandibular joints were the target area of tension, the added emotional complications acted as a feedback mechanism." Temporomandibular joint disturbances and associated muscle pathosis arise from three main causes; physical disturbances during closure of the mandible, physical disturbances during opening of the mandible, and systemic disturbances.

Muscular activity has been called the "fourth dimension" by Martone *(1962)* or the vitality factor of a patient. An understanding of its prosthodontic significance enables the dentist to employ post-operative vision in the treatment planning stage which can minimize denture failure.

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# Changes in the Complete Denture Restoration After Being in Service

*ROBERT M. MORROW*

Changes in complete denture restorations as a result of use can be conveniently classified as *dentist induced* and *patient initiated.* Routine adjustments, relining, and rebasing procedures are the changes the dentist may produce. The patient initiated changes include, but are not limited to, occlusal wear, changes in denture base contours resulting from vigorous cleansing procedures, color changes, and crazing and fouling in the oral environment. The use of patient applied "home reliners" conceivably represents a patient initiated "in use" denture modification and remains beyond the scope of this brief review. For purposes of organization, this review will consider only the following significant factors as direct influences on the service life of a complete denture restoration: **a.** occlusal wear and effects, and **b.** color changes and crazing.

## OCCLUSAL WEAR AND EFFECTS

Porcelain denture teeth have been used by the profession for many years while acrylic resin denture teeth have been in use for about thirty years. The physical properties of porcelain are well documented *(Skinner and Fitzgerald, 1938; Hodson, 1959; Skinner and Phillips, 1967; Norton, 1952; Docking and Chong, 1960).* Porcelain's inherent hardness, inertness, esthetic qualities, and high glazing ability enhance its use in the fabrication of denture teeth *(Seth, 1948).* The desirable properties of acrylic resin for denture teeth include excellent resilience, toughness, natural appearance and feel, plus the capability to chemically bond to the denture base *(Peyton, 1960).*

Low wear resistance of acrylic resin teeth was reported as an advantage if through "wear," the denture becomes "self-adjusting," or "self-balancing" *(Dirksen, 1952),* or a disadvantage if "wear" results in habitual eccentric jaw relationships due to loss of occlusal contours *(Franks, 1962).* Occlusal wear of acrylic resin teeth has been related to the chewing pattern, the periods of time the restorations were in use, and prosthodontic technique. Franks *(1962)* observed that wear of acrylic resin posterior teeth caused



loss of occlusion in centric relation, resulting in the patient assuming a protrusive jaw relationship. He also found that the more satisfactory the dentures were clinically, the more wear occurred on the occlusal surfaces of the teeth. No correlation was found between tooth wear and the length of time the restorations were in use. Others have reported occlusal wear of denture teeth associated with "heavy bites," habits, or in instances where dietary habits included the intake of a high proportion of abrasive foods *(Berry, 1957; Beall, 1943).*

Thomson *(1965)* differentiated in the types of occlusal wear, noting that attrition of occlusal surfaces due to rough foods was characterized by rough surfaces and rounded contours, while habitual grinders or clenchers produced wear characterized by sharp angles and flat polished facets on the occlusal surfaces.

Löfberg *(1957)* reported on twelve patients who wore dentures with acrylic resin teeth for one to two years and found abrasion of the teeth in nine of the twelve patients, four of which were severe in nature. He identified two types of abrasion, one characterized by wear similar to physiologic abrasion that led to a decrease in the vertical dimension of occlusion. The other, related to abrasion between teeth and food, produced flattened occlusal surfaces with a loss of masticating efficiency.

Porcelain seems to resist wear when used as denture teeth. It has been suggested that porcelain teeth, particularly if roughened and unglazed, may produce rapid abrasion of opposing dental gold surfaces, and acrylic resin teeth were suggested for use in this application *(Boddicker, 1947).* Other suggested applications for acrylic resin teeth included those situations where minimal denture space was available, and for removable partial dentures *(Mann and Applegate, 1944).* Metal occlusal surfaces have been advocated by some as a means to avoid undesirable wear or abrasive characteristics of acrylic resin and porcelain teeth *(Koehne and Morrow, 1970; Wallace, 1964; Woodward and Gattozzi, 1972).* The combination of porcelain opposed by acrylic resin denture teeth has been suggested as a method to preserve some of the desirable properties of each material with resultant improvement in denture experience *(Marsh, 1965; Myerson, 1957).* Less wear was said to occur with this combination, and occlusal clicking was minimized *(Sears, 1956).*

Although abrasion of the occlusal surfaces of denture teeth has been noted clinically and reported, objective wear resistance determinations have proven difficult to accomplish. Standard wear-testing equipment has been proven unsuitable for evaluating wear characteristics of denture teeth. Pressure between surfaces, speed, hardness, composition, plus the nature of the environment, e.g., temperature and surrounding fluids, are variable factors which render such testing difficult *(Thomson, 1965).* Various wear test machines have been developed for the purpose of using different types of abrasive slurries *(Boddicker, 1947; Shell, Hollenback and Villanyi,* *1966; Saffir, 1944; Jordan, Cornell, Rose and Justi, 1955; Cornell, Jordan, Ellis and Rose, 1957; Greenwood, 1955).*

## COLOR CHANGES AND CRAZING

There are few references in recent literature concerning discoloration and crazing of denture teeth or base material. Thus, it can be assumed that color change and crazing are infrequently encountered with new and improved materials. Craze resistance and color stability are requirements for acrylic resin denture teeth to achieve certification by the American Dental Association. No similar requirement concerning the crazing of denture base resins is included in American Dental Association Specification 12, Denture Base Polymer. Nondestructive crazing testing procedures for acrylic resin denture bases using fluorcien Na or UV radiation have been reported.

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# Changes in the Relationship of Complete Dentures to the Supporting Tissues

*ANTJE TALLGREN*

The main objective of complete denture treatment is to re-establish the functional conditions of the masticatory apparatus, and to restore the facial proportions and characteristics of the individual, which are determined by the occlusal jaw relationship and the morphology of the natural dentition. Considering the present day advanced methods for construction of complete dentures, the obtaining of satisfactory results would not seem to be a major problem. On the other hand, due to a continuing resorption of the residual ridges during wearing of the dentures, the maintenance of the achieved treatment results constitutes one of the marked prosthodontic problems.

As complete denture occlusion is intimately related to jaw-to-jaw relations and to the positional relationship of the dentures to the supporting structures, post-insertion changes in these relationships will markedly affect the occlusion of the dentures. Therefore, increased knowledge of the pattern of resorption of the residual ridges in denture wearers and the effect of the ridge reduction on complete denture occlusion is of fundamental importance.

## CHANGES IN JAW RELATIONSHIPS

**CHANGES IN OCCLUSAL VERTICAL DIMENSION.** The most obvious effect of the reduction of the residual ridges in complete denture wearers is a decrease in lower facial height when occluding the dentures. The reduction in the occlusal vertical dimension, or overclosure, defined by the Academy of Denture Prosthetics as "a reduced interarch distance when the teeth are in contact," is the consequence of an upward change in mandibular position due to the ridge reduction and the settling of the dentures on the basal seat. This change in vertical jaw relationship, with a resulting forward positioning of the chin in relation to the upper jaw, and accompanying changes in soft tissue profile, have been described in articles and textbooks over the years by Monson *(1921)*, Wright *(1929)*,



Tallgren *(1957)*, Sheppard *(1964)*, and Berry and Wilkie *(1964*.

The application of the roentgenographic cephalometric technique for the study of facial morphologic changes in denture wearers has made it possible to examine more closely the gradual changes in jaw relations related to the ridge reduction. In cephalometric analyses, the occlusal vertical dimension usually is defined as the morphologic face height and determined as the distance between the reference points *nasion* and *gnathion* with the teeth in occlusion.

Longitudinal cephalometric studies of post-insertion changes in facial height in individuals provided with complete upper and lower dentures have revealed a marked decrease in the occlusal vertical dimension *(Thompson, 1946; Tallgren, 1957, 1966; Swerdlow, 1964; Coccaro and Lloyd, 1965; Carlsson and Ericson, 1965, 1967; Ismail, et al., 1968)*. The reduction has been found to be greatest during the first one-half year of denture wear, and thereafter to continue at a gradually slower rate. Observations over a seven-year period *(Tallgren, 1966)* have revealed a pronounced reduction of the morphologic face height to less than the pre-extraction level. No compensating corrections for the decrease in the occlusal vertical dimension had been made during this period. Further analyses of the facial morphologic changes during the seven-year period of observation *(Tallgren, 1967)* revealed that the magnitude of reduction in occlusal facial height approximated the total anterior vertical reduction of the osseous residual ridges. It was further observed that the reduction in the occlusal vertical dimension was mainly due to a pronounced resorption of the lower ridge with a resulting marked upward change in mandibular position and a corresponding increase in mandibular prognathism. The magnitude of these changes, however, showed great interindividual variations.

**CHANGES IN REST VERTICAL DIMENSION.** Changes in the rest facial height, indicative of adaptive changes in the mandibular rest position due to loss of occlusal contacts, and alterations in the occlusal vertical dimension due to complete denture treatment and wearing of the dentures, have been clearly demonstrated in a number of longitudinal cephalometric studies *(Atwood, 1956; Tallgren, 1957, 1966; Duncan and Williams, 1960; Swerdlow, 1964; Fish, 1964; Carlsson and Ericson, 1965, 1967; Nairn and Cutress, 1967; Ismail, et al., 1968)*. Thus, an increase of the pre-extraction occlusal vertical dimension or that of previous dentures has been shown to cause a rapid increase in rest vertical height upon insertion of the dentures *(Tallgren, 1957, 1966; Swerdlow, 1964; Carlsson and Ericson, 1967; Ismail, et al., 1968)*. Moreover, when the increase of the occlusal vertical dimension has exceeded the previous interocclusal distance, the resulting increase in rest vertical dimension has been found to be associated with the establishment of an interocclusal distance at the new level, although mostly of smaller magnitude than the previous rest space *(Tallgren, 1957, 1966; Christensen, 1970)*.

In regard to changes in the rest position during wearing of complete dentures, the decrease in morphologic face height has been shown to be accompanied by a decrease in the rest face height, although somewhat less marked, with a resulting increase in the interocclusal distance *(Tallgren, 1957, 1966; Swerdlow, 1964; Carlsson and Ericson, 1967; Ismail, et al., 1968).* The increase in the interocclusal distance, however, has been found to be small in comparison with the marked reduction in the occlusal and rest facial heights. During long-term wearing of complete dentures, the rest face height, in accordance with the occlusal facial height, has been found to decrease (markedly) to under the pre-extraction level *(Tallgren, 1966).*

As further revealed in studies by Olsen *(1951)*, Tallgren *(1957, 1966)*, Swerdlow *(1964)*, Fish *(1964)*, and Carlsson and Ericson *(1967)*, the rest vertical dimension in complete denture wearers shows an average decrease upon removal of the dentures from the mouth. During long-term wearing of complete dentures the rest vertical dimension without dentures seems to parallel the reduction in rest face height with dentures, and has been shown to decrease below the pre-extraction rest level *(Tallgren, 1966).* From a clinical point of view, the mandibular rest position, due to its inconstancy, does not constitute a reliable reference position for assessment of the occlusal vertical dimension in denture construction, or for evaluation of changes in occlusal face height in denture wearers.

Current concepts on the physiology of the rest position of the mandible and factors which may affect the mandibular posture have been reviewed in the section "The Physiology of Jaw Movements." In regard to changes in rest position in complete denture wearers related to alterations in occlusal vertical dimension, and to wearing or not wearing dentures, the changes in oral conditions and environments should be considered. As previoulsy emphasized by the present author *(Tallgren, 1957, 1966)*, adaptive changes in rest position to alterations in dental and oral conditions may be attributed to a functional demand of the masticatory system for maintenance of an appropriate rest space between the jaws. In this connection, changes in the postural position of the tongue may be of particular significance *(Atwood, 1958; Fish, 1961, 1964 and Berry Wilkie, 1961, 1964).* Further studies for evaluation of these aspects would be of great value.

## POSITIONAL CHANGES OF COMPLETE DENTURES IN RELATION TO BASAL SKELETAL STRUCTURES

Positional changes of complete dentures as a result of soft tissue displacement and destruction of the denture supporting structures are to be considered among the main factors causing alterations in the occlusal relationship of the dentures. Although much interest has been devoted to this problem, the pattern of such changes has not been investigated to any great extent.



Regarding the terminology used for explaining changes in position of complete dentures on the basal seat, Kelsey *(1971)* draws attention to the fact that although "denture 'settling' is one of the most common terms associated with complete denture construction, yet it has been excluded from prosthetic glossaries and textbooks." The term settling is commonly used for explaining the sinking of the denture on the basal seat to a lower level; a change mainly in vertical direction. As described by Boucher, C. O. *(1953)* and others, minor initial post-insertion settling of the dentures may occur due to the resiliency of the underlying mucosa, and may be regarded as a process of adaptation of the dentures to the basal seat. According to Brigante *(1965)*, the term "settling" should be restricted to such minor positional changes. During wearing of the dentures a marked settling may occur as a consequence of soft tissue displacement or mobility, which according to findings by Lytle *(1962)* and Bergman, *et al.* *(1964)* seems to be greater on the mandibular than on the maxillary ridge, and is especially prevelant under ill-fitting dentures. A sinking of the denture to a markedly lower level, however, is mainly due to resorption of the residual ridges. The magnitude of settling in the vertical direction, as measured in the anterior region, has been shown to approximate the osseous vertical ridge reduction *(Tallgren, 1969).*

However, as revealed in studies by Johnson *(1964a, 1964b, 1964c)*, Brigante *(1965)*, and Tallgren *(1969)*, marked horizontal changes and rotational movements of the dentures in relation to the basal skeletal structures are also to be considered. These various changes are described by Brigante *(1965)* as "migration" of the dentures. He studied (cephalometrically) the changes in position of complete upper and lower dentures by means of lead shot reference points imbedded in the denture body. The lower dentures showed a greater total change than the upper ones and were found to have "settled" on the basal seat as bone resorbed. In relation to cranial landmarks, the upper and lower dentures, as a pair, were found to have moved in an upward and forward direction due to overclosure. The vertical and horizontal components of these changes were not analyzed. He further observed that immediate dentures showed greater and more rapid changes than dentures remade upon healed ridges. This occurred in spite of periodic corrections.

Carlsson, *et al.* *(1967)*, in a cephalometric study of the maxillary ridge resorption under immediate complete dentures, compared the position of the central incisors five years after insertion with the pre-extraction position of the corresponding natural teeth. The differences observed indicated a marked forward and upward movement of the anterior part of the dentures despite various prosthetic measures during the period of denture wear. An upward movement of the anterior part of immediate complete upper dentures was noted also by Johnson *(1964a, 1964b, 1964c)* from tracings and superimposition of cephalometric films. This movement, however, seemed to be accompanied by a distal displacement of the denture body. The changes observed were mainly related to the healing period and were only slight during the subsequent observation periods during which relining of the dentures was performed.

The gradual positional changes of complete upper and lower dentures during a seven-year period in relation to the ridge reduction and the change in mandibular occlusal position was studied cephalometrically by Tallgren *(1969)*. The dentures were inserted three months after extraction and no corrections were performed during the period of observation. In regard to the upper dentures, measurements of the position of the central incisors and the inclination of the upper occlusal plane in relation to the cranial base revealed an upward and forward movement of the anterior part of the denture, the vertical component being somewhat more marked than the horizontal. In accordance with the rate of resorption, the positional changes of the upper dentures were greatest during the first half year. Measurements of the position of the lower central incisors and the inclination of the lower occlusal plane in relation to the mandibular body revealed a marked settling of the lower dentures, especially pronounced in the anterior region, and an accompanying forward displacement of the denture on the basal seat. These changes were most marked during the first year of denture wear. The settling of the lower dentures in the anterior region during seven years was, on the average, four times greater than the corresponding vertical change of the upper dentures. As a result of the upward rotation of the mandible, the lower incisal edges were brought further forward in relation to the cranial base. The upward change of the lower incisors in the occlusal position corresponded to the upward change of the anterior part of the maxillary denture. In regard to changes in the incisal relationships of the dentures, the combined effect of the increase in mandibular prognathism and the forward slide of the lower denture on the basal seat led to a decrease in overjet and, in some cases, even to an anterior crossbite. During this course, the vertical overbite showed a less marked reduction.

The problem of denture settling and overclosure and, particularly, the effect of the forward-upward rotation of the mandible on the occlusal relationship of the dentures has been treated among others by Parks *(1930)*, Chick *(1949)*, Fish *(1964)*, Sheppard *(1964)*, Goodkind *(1967)*, and Wright, Lang, Kelsey and Tillitson *(1968)*. Goodkind *(1967)* studied cephalometrically, in edentulous subjects, the mandibular movement in overclosure by means of lead pellets imbedded in trial bases. In the anterior point, the vertical component of the movement was found to be greater than the horizontal, whereas in the posterior point, the horizontal component was identical or greater than the vertical. The study also indicated



that the forward-upward movement of the mandible in overclosure is a hinge type of movement. More information on the complex effect of overclosure and the positional changes of the dentures on centric occlusion is needed.

## LONGITUDINAL STUDIES ON RESORPTION OF RESIDUAL RIDGES

During the past fifteen years, several longitudinal resorption studies have contributed to our knowledge on the response of the residual ridges to complete denture treatment and the wearing of the dentures.

Atwood *(1957)* studied (cephalometrically) the total anterior vertical bone loss of the residual ridges in complete denture wearers. He found a measurable ridge reduction in the majority of the subjects during post-insertion intervals varying from five to forty-six months. The magnitude of reduction, however, showed greater interindividual variations.

In order to obtain further information on the pattern and amount of resorption under complete dentures, studies have been performed on various samples; the effect of different methods of treatment has also been examined. Special interest has been devoted to analysis of changes in contour of the maxillary process under complete upper dentures *(Watt, 1960; Hedegård, 1962; Wictorin, 1964; Johnson, 1963, 1964a, 1964b, 1964c, 1967; Carlsson, et al., 1967)*. In these studies, the dental status of the lower jaw in most instances has been natural teeth with or without a partial denture.

Regarding the response of the alveolar ridges to different types of treatment, Johnson *(1963, 1964a, 1964b, 1964c)* analyzed the dimensional changes in the anterior maxillary ridge by means of measurements on casts, and Wictorin *(1964)* conducted a cephalometric study of the anterior maxillary bone loss. Both studies revealed a smaller ridge reduction in subjects provided with immediate upper dentures than in those provided with dentures after a healing period of some months. The difference in resorption between the two treatment groups observed by Wictorin, however, seemed mainly to be related to the initial healing period. In both these studies the rate of reduction showed a marked decrease after the healing period. Wictorin, at a three-year follow-up examination of part of the subjects, noted a continued reduction, although at a much reduced rate. Johnson *(1967)*, in about half of the subjects, observed a stabilization of the resorption during the second year; in the remaining subjects, continued reduction was observed at the three-year examination despite various prosthetic measures during the period of denture wear. In a five-year cephalometric study by Carlsson, Bergman and Hedegård *(1967)* on changes in contours of the anterior maxillary ridge under immediate complete upper dentures, a continued reduction, although at a much reduced rate, was observed at the five-year follow-up. The mucosal and skeletal contours were found to have changed largely to the same extent. The vertical, palatal, and labial reduction showed great individual variations.

The reduction of the anterior mandibular ridge during a five-year period was studied by Carlsson and Persson *(1967)* in subjects with immediate complete lower dentures, and in subjects provided with lower dentures two months after extraction. No significant differences in resorption were observed between the two treatment groups. In the posterior segments, the ridge reduction was found to be less marked than in the anterior region and to diminish with the distance from pogonion.

A comparison of the maxillary and mandibular alveolar bone loss during long-term wearing of complete dentures *(Tallgren, 1967, 1969)* revealed a marked difference in magnitude and pattern of resorption between the jaws. While the reduction in height of the anterior upper ridge displayed a marked retardation after the first half year of denture wear, the lower ridge showed a continued marked reduction, although at a gradually decreasing rate. In the posterior segments, the reduction was markedly less than in the anterior region. The relationship between the anterior reduction of the mandibular and maxillary ridges gradually increased to four to one at the seven-year stage. A similar relationship in the mean rate of reduction between the jaws was observed by Atwood and Coy *(1971)* in a study of the post-extraction anterior vertical bone loss in complete denture wearers.

In a follow-up study by Tallgren *(1972)* of subjects from the seven-year study to the fifteen-year stage, and of another sample from the ten-year to the twenty-five-year stage of wearing complete dentures, a continuing reduction of the residual ridges was observed. The reduction in anterior height of the mandibular ridge was, as previously, about four times greater than that of the upper ridge. During the protracted wearing of dentures the mean rate of resorption for the upper and lower ridges was only one tenth of that observed during the first year. As judged from the findings of this semilongitudinal study, the reduction in height of the lower ridge during a twenty-five-year period would amount to an average of ten mm., and that of the upper ridge to three mm. This progressive and extensive resorption of the residual ridges is a serious prosthodontic problem and, as emphasized by Atwood *(1971)*, "results in repeated mucosal, functional, psychologic, esthetic and economic problems for denture patients."

**INDIVIDUAL VARIATIONS IN RIDGE RESORPTION.** In the longitudinal studies on ridge reduction reviewed in the foregoing, large individual variations in amount of resorption have been observed. Interest, therefore, has been devoted to analysis of possible relationships between the magnitude of resorption and some biologic, anatomic, and prosthetic factors.



In analyses by Wictorin *(1964)*, Carlsson, *et al.* *(1967)*, Carlsson and Persson *(1967)*, Tallgren *(1970)*, and Atwood and Coy *(1971)*, no definite associations were observed between resorption, age, or sex. Nor were any marked relationships noted between resorption and the size of the alveolar ridges. In the study by Carlsson and Ericson *(1967)*, no significant association was observed between resorption and the pre-extraction periodontal status. Furthermore, in the study reported by Atwood and Coy *(1971)*, analyses of the relationship between bone density and the mean rate of reduction of the residual ridges revealed no definite tendencies.

In regard to prosthetic factors studied, one factor of considerable interest is the effect of alterations in occlusal vertical dimension on the ridge resorption. Many of the analyses reported, however, are based on studies of the facial height. Thompson *(1946)* made the observation that an increase of the occlusal vertical dimension of the dentures beyond the rest facial height resulted in a marked decrease of the morphologic face height, whereas no reduction was observed when the rest vertical dimension was not exceeded. Carlsson and Ericson *(1965)* and Bergman, *et al.* *(1971)* reported similar findings in subjects for whom new dentures had been made. The authors pointed out, however, that the results may be ascribed to other factors. Atwood *(1957)*, on the other hand, in a study of the ridge reduction in complete denture wearers observed no definite associations between the increase in facial height and the resorption. Tallgren *(1966)* in a seven-year study of changes in face height in complete denture wearers found no significant correlations between the increase in occlusal vertical dimension and the subsequent reduction in morphologic face height. On the other hand, in individuals provided with complete upper and partial lower dentures, a significant relationship was observed. These findings were confirmed in analyses of the alveolar bone loss in relation to the increase in occlusal vertical dimension in the same samples *(Tallgren, 1970)*.

In regard to the habitual use of the dentures, observations by Carlsson and Persson *(1967)* and Atwood and Coy *(1971)* revealed tendencies to somewhat greater resorption in subjects who used their dentures day and night than in those who used their dentures only during the day or for several hours. On the other hand, in a study by Bergman, *et al.* *(1971)*, no significant difference in mandibular resorption was observed between the two above-mentioned categories of denture wearers.

As reviewed in the foregoing section, longitudinal observations on residual ridge resorption have indicated that the reduction of the ridges may continue despite periodic corrections or remaking of the dentures. Wictorin *(1964)* even observed a tendency to somewhat greater maxillary labial bone loss in subjects for whom relining of the dentures had been performed. Further investigations of this problem are indicated.

In Tallgren's *(1970, 1972)* cephalometric analyses of the relationship between the anterior alveolar bone loss and morphologic characteristics of the facial skeleton, a significant relationship was observed between the shape of the mandible and the resorption, especially the lower ridge. A pronounced resorption was seen in subjects with a marked mandibular base bend and a small gonial angle, and a less marked resorption in subjects with a flattened mandibular base and a large gonial angle. In regard to the load transmitted to the structures underlying the dentures, one important factor to be considered is the muscular force. Reference should be made to electromyographic findings by Møller *(1966)* of a strong activity of the masseter and the anterior temporal muscles during forced closure in dentulous individuals with a marked mandibular base bend and a small gonial angle. The particularly marked resorption of the mandibular ridge, observed in the complete denture wearers, would seem to indicate that the lower ridge is more likely to respond to the various functional forces transmitted through the dentures than the upper ridge. The most likely reason for this is the smaller area and less advantageous shape of the lower basal seat. In regard to the less marked resorption of the upper ridge, the resistance offered by the hard palate to the influence of the dentures on the alveolar ridge may play an important part.

Further analyses by Tallgren *(1970)* on the relationship between alveolar bone loss and the anteroposterior position of the incisors indicated that a more lingual positioning of the incisal edges of the artificial lower incisors than that of the natural teeth may contribute to the anterior mandibular resorption. In regard to this finding, a change in tongue position may be considered.

Although much information has been obtained on the pattern of reduction of the residual ridges in complete denture wearers, and on factors which may contribute to the ridge resorption, numerous problems still remain unsolved. From the aspect of post-insertion changes in relation to complete denture occlusion, problems which seem to require further research are; the effect of overclosure, impaired denture stability and occlusal changes on the resorption of the residual ridges, and the effect of the ridge resorption on denture occlusion. Moreover, from a clinical point of view, the repeated corrections of the dentures over the years due to the continuing reduction of the residual ridges, constitutes a marked and important problem.



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# SECTION REPORT

## INTRODUCTION

This report is a consensus report reflecting the majority opinion of our Section members based on clinical observations and research documented evidence.

### *Questions Considered by This Section for Post-Insertion Changes in Relation to Complete Dentures Were:*

1. What is the definition of denture base settling?
2. What factors influence denture base settling?
3. What are the post-insertion changes that occur in soft tissues of denture supporting structures or the musculature?
4. How is the bone morphology of residual ridges affected by post-insertion change?
5. How do post-insertion changes affect maxillomandibular relations?
6. How is the temporomandibular joint affected by post-insertion changes?
7. How do post-insertion changes affect functional capability of the complete denture patient?
8. What corrective procedures are recommended to compensate for post-insertion changes?
9. In what areas should research effort be directed?

## DEFINITION OF DENTURE BASE SETTLING

A consensus definition for denture base settling was; "Settling of dentures is the positional change of the denture bases in relation to, and primarily toward, the basal bone. Initial changes are mainly limited to soft tissues while long term changes involve both bone and soft tissues."

## WHAT FACTORS INFLUENCE DENTURE BASE SETTLING?

The numerous factors capable of influencing denture base settling and their complex interreactions render enumeration and classification difficult. The following classification includes some, though not all, of the pertinent factors.

**BIOLOGIC FACTORS.**

1. Age
2. Sex
3. Systemic factors: **a.** genetic, **b.** metabolic, **c.** nutritional, **d.** hormonal, and **e.** pathologic
4. Anatomical factors: **a.** bone, **b.** muscles, and **c.** soft tissues
5. Psychological factors
6. Local factors

**BIOMECHANICAL FACTORS.**

1. Extension and contour of the denture base
2. Form of the impression surface of the denture
3. Physical properties of tooth and base materials
4. Maxillomandibular relations
5. Tooth form, size, and arrangement
6. Occlusion factors

**A TIME FACTOR**

1. The length of the time the patient has worn the dentures.
2. The hours each day the denture is worn.

Clinical observations by many experienced Prosthodontists strongly suggests a positive relationship exists between the above factors, alone or in combination, and post-insertion change. Research directed specifically toward each factor is notably limited with results that are often only suggestive. Specific areas for further research efforts will be presented in a later section of this report.

## WHAT ARE THE POST-INSERTION CHANGES THAT OCCUR IN THE SOFT TISSUES OF DENTURE SUPPORTING STRUCTURES OR THE MUSCULATURE?

**SOFT TISSUES AND POST-INSERTION CHANGES.** Soft tissues of denture supporting structures are deformed by the placement of a complete denture. In some instances this deformation compensates and disguises improper contour of the impression surface of the denture, or occlusal errors. Research indicates that the thickness of soft tissues overlying residual ridges is a factor which varies between individuals and in different areas of the same individual. The development of freely displaceable soft tissues overlying the residual ridges of long-term denture wearers may be a result of the loss of bony support in these areas. This remains a clinical impression, the validity of which remains to be determined. Pathologic conditions may also influence the soft tissues of denture supporting tissues. Papillary hyperplasia, denture sore mouth, epulis fissuratum, and other entities produce changes in the tissues which may influence denture function.

The histopathology of soft tissue changes was not considered by this Section.

**MUSCLE AND POST-INSERTION CHANGES.** In regard to the load transmitted to the structures underlying dentures, muscle force is a factor to be considered. Muscular development may be strong, or relatively weak, as in the senile patient. The lower ridge responds to the various functional forces transmitted through dentures more than the maxillary ridge. This may be due to the smaller area and less advantageous shape of the lower basal seat. The resistance of the palate may be a significant factor in the less marked resorption of the upper ridge.



## HOW IS THE BONE MORPHOLOGY OF RESIDUAL RIDGES AFFECTED BY POST-INSERTION CHANGE?

The literature related to post-insertion change in residual ridges was reviewed extensively by Tallgren and the Section members felt it was not necessary to reproduce her literature review in this report. It is the consensus opinion of our Section, however, that reduction of residual ridges in complete denture wearers does occur and perhaps its most obvious effect is a decrease in the lower facial height when occluding the dentures. The change in vertical jaw relationship, with a resulting forward positioning of the chin in relation to the upper jaw, and accompanying changes in the soft tissue profile, have been described in numerous articles and textbooks. Reduction has been found to be greatest during the first one-half year of denture wearing and thereafter to continue at a slower rate. Reduction of the occlusal vertical dimension is due mainly to a pronounced resorption of the lower ridge. The settling of the lower denture is approximately four times greater than the corresponding vertical change of the upper dentures. Change seems to be greater during the first year of denture wearing and appears to be greatest in the anterior residual ridge area, particularly when opposed by natural teeth. There is great individual variation in resorption patterns, with contour modifications occurring on buccal, lingual, and ridge crest areas. Clinical observations suggest the gradual enlargement of tuberosities of some denture patients in which a "vacuum" effect of the denture may be a possible causative factor. The numerous etiologic factors with their complex interrelationships remain a perplexing area of study for the researcher.

## HOW DO POST-INSERTION CHANGES AFFECT MAXILLOMANDIBULAR RELATIONS?

Change in the positional relationship of the maxilla to the mandible was discussed previously under post-insertion changes of the soft tissues, muscles, and bone. A reduction in the occlusal vertical dimension occurs with a concomitant, essentially rotational, movement of the mandible upward. This produces the characteristic upward change in mandibular position with a resultant forward positioning of the chin in relationship to the upper jaw. Although this movement is perhaps best described as rotational, a translational component may be involved, particularly in those patients who shift the mandible forward into a position of convenience and comfort at the reduced vertical dimension of occlusion. This remains primarily a clinical observation.

## HOW IS THE TEMPOROMANDIBULAR JOINT AFFECTED BY POST-INSERTION CHANGES?

Although research results are conflicting, it was the consensus opinion of the Section that post-insertion changes, accompanied by a decrease in the vertical dimension of occlusion and resultant occlusal discrepancies, may precipitate or perpetuate temporomandibular joint dysfunction.

## HOW DO POST-INSERTION CHANGES AFFECT FUNCTIONAL CAPABILITY OF THE COMPLETE DENTURE PATIENT?

A post-insertion change in which there is a decrease in the occlusal vertical dimension may result in increased force application to the anterior portion of residual ridges with a resultant infraocclusion of the posterior teeth. This is often accompanied by undesirable positional changes of the denture base in relation to the denture foundation. Horizontal overlap of anterior teeth may be reduced, and in severe instances, the mandibular anterior teeth may be in a forward position in relation to the maxillary anterior teeth. There is no scientific evidence to support the fact that selected occlusal patterns of the denture teeth will prevent the above. A reduction of the occlusal vertical dimension may also result in a decreased masticatory force. A reduction of occlusal vertical dimension to



attempt to reduce forces and promote comfort, deserves investigation. A decreased vertical dimension of occlusion may be accompanied by an undesirable esthetic result, which is difficult to study objectively. A reduction of the occlusal vertical dimension with an increased interocclusal rest space may affect the stability and retention of the complete denture restoration.

Complete denture function may be compromised due to discomfort resulting from pressure of the denture upon unprotected neurovascular bundles.

## WHAT CORRECTIVE PROCEDURES ARE RECOMMENDED TO COMPENSATE FOR POST-INSERTION CHANGES IN COMPLETE DENTURES?

Corrective procedures to compensate for post-insertion changes include adjustments and modifications of the denture base and/or occlusion. If the denture base is to be altered through relining or rebasing, the soft tissues should be returned to the best possible form and health prior to impression procedures. Occlusal errors that develop during the wearing of dentures should be corrected at periodic intervals in order to maintain the health of denture foundation tissues. Scheduled recall appointments for every complete denture patient are recommended. Although requirements vary, each complete denture patient should be seen at least annually. Others will require more frequent appointments. Patients with denture-abused tissues, papillary hyperplasia, epulis fissuratum, or other disease entities, should be treated by accepted methods to restore tissue health before relining or remaking the denture. Specific criteria for determining whether relining, rebasing, or remaking of the denture is required, involves the clinical judgment of the dentist and criteria may vary from one patient to another. Treatment dentures, tissue treatment materials and muscle conditioning exercises may be used to rehabilitate the complete denture patient with post-insertion changes.

In view of the problems experienced by complete denture patients, additional efforts should be made to significantly reduce the rate at which patients become edentulous. Where removal of natural teeth is deemed necessary, it is desirable that surgical procedures be planned and executed which results in a minimal reduction of alveolar bone.

## IN WHAT AREAS SHOULD RESEARCH EFFORT BE DIRECTED?

1. The effect of age on post-insertion change of the residual ridges
2. The effect of nutrition on post-insertion change of residual ridges

3. Relationship of masticatory force and muscle activity in relation to settling of the dentures
4. The effect of systemic factors on post-insertion changes
5. The effect of chronic inflammatory process in the mucosa on post-insertion change
6. The effect of pre-existing periodontal disease in bone changes in the complete denture patient
7. Relationship of relining procedures and residual ridge resorption
8. The effect of porcelain teeth versus acrylic resin teeth in residual ridge resorption
9. The effect of denture base materials on residual ridge resorption
10. The role of bruxing and clenching in post-insertion change
11. A comparison of various relining procedures related to post-insertion change
12. Occlusion and its effect on post-insertion change
13. Temporomandibular joint dysfunction related to post-insertion change
14. Resorption patterns in various locations of denture supporting tissues

Respectfully submitted,

Robert M. Morrow, *Chairman and Reviewer*
Robert B. Lytle, *Secretary*
James T. Jackson, *Reviewer*
Antje Tallgren, *Reviewer*
Ralph H. Boos
Gunnar E. Carlsson
Jacques Fiset
Phillip M. Jones
John D. Larkin
Lennart Wictorin
Gary W. Johnson, *Section Assistant*

# DISCUSSION OF REPORT

Following chairman Morrow's reading of the report, Larkin moved that it be accepted. The motion was seconded by Boos and passed by the General Assembly.

## RE: FACTORS THAT INFLUENCE DENTURE BASE SETTLING

Ramfjord proposed that all of the items under biologic, biomechanical, and time factors be listed under research because it is misleading to present these as known facts.

## RE: POST-INSERTION CHANGES IN SOFT TISSUE AND MUSCULATURE

Woelfel felt an additional comment was required to indicate that papillary hyperplasia, denture sore mouth, epulis fissuratum, etc., are caused by the dentures. He felt that the present wording leads one to think that these are conditions which produce changes in the tissues. Rather, they are changes in the tissue which must be eliminated or removed before new dentures are constructed. Morrow felt the Section members would agree with Woelfel's comment.

## RE: MUSCLE AND POST-INSERTION CHANGES

Henderson requested clarification of the statement, "The lower ridge responds to the various functional forces transmitted through dentures more than the maxillary ridge." Morrow indicated that support for this statement could be found in the research findings reported by Tallgren *(1972)*. Unsatisfied, Henderson continued his questioning by asking, "responds to what?, how?" Tallgren suggested that the statement read, ". . . responds by resorption." Henderson approved this change. The altered sentence would read, "The lower ridge responds by resorption to the various functional forces transmitted through dentures to a greater degree than does the maxillary ridge."

## RE: BONE MORPHOLOGY OF RESIDUAL RIDGES AFFECTED BY POST-INSERTION CHANGES

Weinberg asked if there was a change of rate in bone loss following the insertion of subsequent dentures. Wictorin stated that personal studies indicate that even when new dentures are constructed for patients that have been wearing dentures, there is greater resorption during the first one-half year following insertion.

## RE: POST-INSERTION CHANGES AND FUNCTIONAL CAPABILITY

Ramfjord questioned the statement, "There is no scientific evidence to support the fact that selected occlusal patterns of the denture teeth will prevent the above." He stated that if there is no scientific evidence to support it, it cannot be a fact.

## RE: CORRECTIVE PROCEDURES TO COMPENSATE FOR POST-INSERTION CHANGES

Ramfjord asked if studies were available in prosthodontics to establish the basis for time intervals for the recall of denture patients. Morrow indicated that the Section members were not aware of any such studies.

Wictorin commented that from his clinical observations and research, denture patients should be recalled and examined sooner than one year after delivery, but that following the first year, annual recall should suffice.

Woelfel stated that two studies, one conducted at the Bureau of Standards, and another at Ohio State University, School of Dentistry, indicated that during annual recalls, the examiners, "almost routinely found something that either needed to be done or that we did do in the correction of the occlusion or the dentures or the relationship of the tissue-bearing surface of the denture base to the tissues." He advocated recalling denture patients at least once a year.

## RE: IN WHAT AREAS SHOULD RESEARCH EFFORTS BE DIRECTED?

Zander questioned the use throughout these statements of the words *in* and *on*. He indicated that there is a difference in the meaning in the English language between *in* and *on*, and as a Periodontist, he was quite sensitive to their interchangeable use. "Too many people have talked about periodontal disease 'in' bone and I was quite satisfied to sit quiet until you changed the 'on' to 'in' in your reading of this report." Morrow had no objections to changing the statement (#6) to read, "The effect of pre-existing periodontal disease *on* bone changes in the complete denture patient."



### REFERENCES

Tallgren, Antje. The continuing reduction of the residual alveolar ridges in complete denture wearers: A mixed-longitudinal study covering 25 years. *J. Prosth. Dent.*, 27:120–32, Feb. 1972.

SECTION VII

# Human Factors as Related to Complete Denture Occlusion

## Review of Literature

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## Section Report

## General Assembly Discussion

# REVIEW OF LITERATURE

*CHARLES C. SWOOPE*

## INTRODUCTION

There are many factors which contribute to the success of dental treatment. The technical skill of the dentist is only one item in long-term satisfaction of the patient. This review will deal with human factors and how they influence denture acceptance. The emphasis will be placed on needs of the total patient, and how these needs influence the function of appliances.

Human factors are very important in the successful treatment of edentulous patients. Each patient brings with him a frame of reference based on previous experiences. In addition, he brings a physical make-up which is unique to him. These factors, as well as technical procedures provided by the dentist, will help determine the success of dental treatment. The potential for success or failure will depend on all of these contributory aspects and failure can result by ignoring any one of them.

The final result of treatment will be enhanced or jeopardized, dependent on the ability of the dentist to use all available information about the patient *(Jamieson, 1960)*. The presence of unfavorable human factors can defeat the most conscientious dentist. Since the success of treatment may depend on human factors, it is imperative that the dentist increase his capability to determine the needs and wishes of patients. There is a definite need to identify potential problems early. The plan of treatment can then be designed to meet the needs of the patient: physical, emotional, and functional.

There is a great need for prosthodontic care in the United States. It was estimated in 1962 that there were 111 million adults, age eighteen to seventy-nine years. Of these, 20 million (18 percent) were completely edentulous. An additional 8.9 million (8 percent) were edentulous in one jaw *(U.S. National Center for Health Statistics, 1967)*. As expected, the incidence of edentulous young adults (eighteen to twenty-four years) was low (1 percent) and tooth loss increased with age (sixty-five years and older was 50 percent). The fact that this great need for prosthodontic care exists poses a challenge to dentistry. This large population segment requires a special type of dental care. It is care which must consider the total patient—his needs and wishes. This area of dentistry is one where human factors are very important. In many instances, the success of treatment will depend on human factors, not technical skill.

Approximately 80 percent of these patients have dentures that function with varying degrees of success. They have sought care in search of comfort—both physical and mental. Whether this objective will be met will depend on human factors and technical factors. It has been observed that treatment executed in a brilliant manner can fail because of human factors. It also has been noted that half of the dentures will be satisfactory to the patient in spite of poor technical procedures *(Young, 1949)*. The problem of meeting the needs of a large, primarily elderly population is dependent on meeting the emotional as well as masticatory needs of the patient.

The potential for success depends on the ability of the dentist to interpret and predict needs of the total patient. There is no question that unconscious emotional problems can lower the chances of success. It is imperative that potential problems be identified early, before treatment begins. Adequate communication and prognostic devices must be employed to plan treatment and assure realistic expectations.

It has been stated that the edentulous population is found primarily in older age groups. These patients have particular problems, both physical and emotional, which must be considered in planning treatment. The values of dentures for the patient may not be the same as values of the dentist. There may be different priorities on objectives such as appearance, function, and preservation *(Young, 1957)*.

The restoration of missing structures is not only to restore simple mastication. It has been estimated that only 20 percent of food requires vigorous mastication. In fact, if comminution is the primary objective, many machines can perform this with much greater efficiency than complete dentures *(Young, 1957)*. The values of appliances are much greater than improvement of masticatory function since they permit the individual to continue to function as a person in a productive manner. The dentures will aid a variety of physical and emotional deficiencies.

The general population continues to increase and so does the patient-dentist ratio. There were 150 million people in the United States in 1953, increasing to 198 million in 1967 (an increase of 24.5 percent). The dentist-patient ratio was 50:100,000 in 1950 and 46:100,000 in 1967 *(U.S. Bureau of the Census, 1969)*. The need for dental care increases while the dentist-patient ratio decreases. In order to provide care for the great numbers of edentulous patients, more effective and efficient methods must be developed. This cannot be done at the expense of ignoring human factors. There can be some simplification of technical procedures *(Smith, 1970)*, but certain procedures cannot be streamlined. The strong dentist-patient



relationship must be maintained or the treatment will fail. There must be a mutual atmosphere of confidence and this cannot be delegated or ignored. There are procedures proposed to help meet the increased demand for high quality care at lower cost. These demands by large population groups can result in government intervention if not heeded. When simplified procedures are advocated, it is important that the patient not be ignored. Important steps such as diagnosis, clinical try-in, and after-care will remain unchanged. Esthetics will always be important and the use of simplified occulusal patterns will have to consider patient requirements. Dentistry needs more efficient procedures to deliver prosthodontic care while maintaining a high level of awareness of the importance of human factors *(Smith, 1970)*.

Each patient brings with him a particular set of characteristics. His frame of reference will depend on his background and environment. Everyone has fears and needs but these vary with personality differences of people just as there are differences in age, sex, intelligence, etc. In addition to emotional differences, the patient brings differences in physical characteristics. Such things as general systemic condition, tissue tone and quality, muscle coordination, and a host of others will have an influence on prognosis. Physical and mental factors help determine adaptive capabilities of patients and their ability to cope with tooth loss and appliances.

The objective of dentistry is to maintain the anatomic, physical, and mental condition at the highest physiologic level *(Principles, Concepts, and Practices in Prosthodontics, 1963)*. The basic objective is not just to restore missing teeth but to restore the total patient to resume his role as a functioning productive member of society. Th restoration of these large groups of patients is the challenge of dentistry *(U.S. Public Health Service, 1960)*. Many do not receive regular care and the type of care varies with human factors such as income, race, education level, etc.

Emotional factors can influence the presence and cause of disease. There are many variables in disease onset, including intermediary physiological mechanisms, which are largely unknown. Generally, emotional aspects are correlated but are not the complete etiology *(Alexander, 1961)*. Onset depends on constitutional factors, psychological patterns in early life, and precipitating life situations. It is obvious that comprehensive treatment cannot ignore the psychological components. Somatic treatment alone will seldom provide a permanent remedy. A knowledge of psychosomatic correlations is needed in order to combine medical, dental, and psychological therapy *(Alexander, 1961)*.

Emotional factors can precipitate dental symptoms. The reason for seeking dental care may be a symptom with at least partial emotional etiology. These types of dental-related problems may include: periodontal disease, facial pain, paresthesia, bacterial invasion, xerostomia, bruxism, and many others *(Moulton, 1955)*. Specific disease processes and human factors will be discussed in detail in another section of this review. The purpose at this point is to identify the problem and define the influence of human factors in general.

When a patient seeks care, we must carefully evaluate his condition and his needs. His behavior may have a profound effect on his physical condition and success of treatment *(Borland, 1962)*. The emotional significance of the face to a particular patient will determine his values for treatment.

The environment, congenital factors, and systemic factors will influence the interrelated group of characteristics presented by the patient. The dentist must establish adequate communication, determine the needs and wishes of the patient, carefully plan the treatment, and provide care for the whole patient. Physical and emotional needs must be met for a successful outcome. Care will include therapy, both technical and supportive, during an adjustment phase and into the maintenance phase.

The primary objective of dentistry must be total patient care, not specific technical remedies for local problems.

## BODY IMAGE

Every person has a mental picture of his own appearance. This body image is how we view ourselves *(Beder, 1971)*. This concept of ourselves has been present for many years and most people are comfortable with it. It might not represent the best possible body or face, but people have become adjusted to it. Even though it might not be perfect, there is considerable resistance to change. In fact, the idea of change may be a threat to the patient and result in anxiety *(Miller, 1970)*.

It is not surprising that patients will view the impending loss of teeth with fear and dread. The emotional response to a planned extraction may be out of proportion and inappropriate. The significance of the face area cannot be overemphasized since people have pride in their face and will experience an emotional response to any threat or procedure in that area *(Wilson, 1932)*. The oriental expression "loss of face" typifies the importance of the area to the individual. His personality is reflected by the face. It is the part of his inner self that he presents to others. It is not surprising that anxiety can easily result in functional disturbances of the face area.

Some patients are unhappy with their body image. These persons are very anxious and would like to make a change. Their requests may be unreasonable and the dentist should be very cautious. These individuals frequently experience many emotional disturbances. They have tended to focus their anxiety on the face area through somatic symptoms or a distorted self-image. They feel that if their appearance was changed



to meet their anticipated self-image, their problems would disappear. Of course, the problems do not change with the change of appearance. These patients cannot accept the fact that they are contributing in any way to their problems. Since the problems still exist, then the denture must obviously be at fault. Later sections of this review will deal with patient communication and realistic objectives. It is easy to see how the denture has little chance of success when it is expected to provide a change in body image and life style.

Esthetics in denture construction is related to body image. Patients have a mental picture of their own body. For the denture to be successful, this body image must be communicated to the dentist. Most patients are acutely aware of appearance and will place the highest priority on this objective. Since esthetics is a sensation and emotion, it is difficult to elicit specific information. Our feelings about what is pleasing is based on our traits, feelings, actions, and attributes of the mind *(Brewer, 1970)*.

Most patients would rate appearance as the primary objective of dentures, followed by comfort, with chewing ability being of lesser importance. The dentist must keep this in mind when the patients come in saying they are really not interested in appearance but just want to chew their food. In most instances this is not true. Men may be reluctant to express concern over appearance. It may not seem masculine to be overly concerned with esthetics, and it is more socially acceptable to be concerned with comfort. It is essential not to accept these superficial statements as justification for remaking dentures when the underlying reason may be something else. If the patient or his family are not satisfied with appearance, a long period of post-insertion care can be anticipated. Complaints will usually concern discomfort or poor mastication. Obviously, nothing the dentist can do will improve the denture acceptance since he is not treating the real problem of appearance.

Most patients desire a pleasing natural appearance which is similar to their appearance with natural teeth. In contrast to the anxious patient who desires a change, most patients desire an unobtrusive appearance. Esthetics is based on factors of sex, age, and personality. Dentures should be neither a detriment nor an adornment *(DeVan, 1957)*. As the eye passes over a denture, attention should not be attracted in any way. The teeth should blend in with the face and just appear "like natural teeth." If the attention is attracted, the observer comes back for a second look and wonders if it really is a denture. Teeth that are too light, too straight, too small, etc., all attract attention and contribute to a "denture look."

The dentist must consider patient wishes but cannot be forced into decisions that are technically incorrect. This is especially true with patients who have a distorted body image. The psychologic limitations imposed by the patient results in esthetic problems. Their sensitivity toward aging and appearance deficiencies is great. This is particularly manifest in the orofacial region of edentulous patients *(Young, 1955)*.

Because appearance and body image are individual personal concepts, there needs to be harmony between patient and dentist *(Lefer, 1971)*. It is necessary for the dentist to be perceptive of the patient's body image and the patient to be comfortable and confident of the dentist. In most instances, the correct place to begin is with a tentative tooth position which duplicates the natural teeth of the patient *(Smith, 1971)*. In fact, it has been stated that except in the presence of pathology, the only correct tooth position is where they were in nature. This emphasizes the need for pre-extraction records. There are ways to keep appearance relatively unchanged and this topic will be discussed in the section on methods of tooth replacement. Most patients are threatened by a change in appearance which would require a revision of their body image. Since appearance and success are closely related, it is logical to retain similar appearance in most instances.

Patients with congenital and acquired defects have particular problems with body image. There is psychological trauma both to parents and patients *(Cooper, et al., 1960)*. It is important that adequate information be transmitted to allow acceptance of the deformity and optimism for correction. A physical handicap is not necessarily a social handicap. The body image of these patients may be somewhat distorted, and counseling may provide a more realistic concept of self. The multidiscipline approach to treatment of patients with defects has provided rehabilitation, not merely correction of the defect. This topic will be discussed further in a later section.

Our body image has been influenced by our surroundings. The face is a remarkable social signal, with a frown or smile *(Ament and Ament, 1970)*. We are surrounded with advertising of mouths that are "kissing sweet" or have "sex appeal." The influence on how we visualize ourselves is dramatic, both as we are now or will be. When teeth are missing, something close to our psyche is gone *(Landa, 1953)*. This is more than loss of the physical organ of mastication, but a disorganization of the total personality. Changes involve speech, eating, and appearance with embarrassment and apprehension. These kinds of forced revision of body image are traumatic and usually result in anxiety or depression. These reactions are normal, unless prolonged, and the dentist must respond to them. A successful conclusion will depend on reassurance and confidence that the revision in body image will be minimal. There is a need for adaptation and this must be carefully discussed with the patient. Their fears and apprehensions must be verbalized. A rational discussion can supply needed information to reduce worry, anxiety, and fear and the reassured patient will feel great relief. Success can only occur when the patient's body image is considered when the treatment is planned.



## PERSONALITY AND ORAL DISEASE

Emotional factors can precipitate or aggravate dental symptoms. Anxiety can produce somatic symptoms of the face area which may become chronic in nature *(Wilson, 1932)*. The change in behavior is often out of proportion to the symptoms. The increasing tensions of our culture produce increased psychosomatic symptoms *(Moulton, 1957)*. Since the mouth is the expression of our emotions, anxiety and frustration frequently somatize to the mouth *(Heaver, 1947)*. Patient responses can vary from a violent over-reaction to an indifferent or flat response.

There are various categories of oral disease which are related to emotional factors. Periodontal disease can be associated with overt habit patterns with the teeth, unusual food habits, or unusual response to dentists and dental care. There may be symptoms with the absence of tissue damage, including facial pain and paresthesia. Dysfunction of the autonomic nervous system can result in vascular changes which permit bacterial invasion or changes in salivary rate. Oral habit patterns such as bruxism can result in pain, joint dysfunction, muscle spasm, and tissue changes *(Moulton, 1955)*.

Psychosomatic or psychophysiologic problems in the face reflect the significance of the area. There may be no organic disease present with symptoms resulting from anxiety. Tension is the prototype to anger and hostility, which if continued will result in anxiety *(Kaplan, 1958)*. The disorders may be psychophysiologic and result from tension with no symbolic meaning (example: ulcer has no symbolic meaning but is the end product of continued tension). These patients have no conscious anxiety and feel they have no emotional problems. Neurotic disorders are typified by the presence of anxiety and symbolic meaning of the symptoms. All patients vary in their psychological traits and defenses which causes different responses.

**FACIAL PAIN.** Facial pain is the most common somatic symptom. It is also the most difficult. It cannot be seen, measured, or removed. It is difficult because the therapist must depend on verbal descriptions of the patient to obtain information. The pain can vary in location from the head, face, palate, tongue, neck, and shoulder. It may radiate and give sensations of pressure, vertigo, and blindness. The distribution is important to differentiate a neurologic etiology from an emotinal etiology. The emotional etiology is more common and does not follow an anatomic distribution.

Psychogenic factors are important but the therapist must use restraint and not overlook possible organic etiologic factors *(Weisengreen, et al., 1954)*.

An understanding and humanitarian approach is required to establish stability in the dentist-patient relationship. It is important not to oversimplify the complex etiology of facial pain. It is not justified to divide it into simple psychic and somatic causes since the human is one functional unit *(Walsh, 1953)*. The patient with pain is difficult to manage since the causes are obscure and the patient is alarmed by not understanding the problem *(Schwartz, 1955)*.

Atypical facial neuralgias have been difficult for both the dentist and the patient. The pain does not follow the trigeminal distribution and there are no demonstrable lesions *(Engel, 1951)*. This pain is most common in women and commonly is a conversion symptom. They frequently have had considerable misfortune and are depressed. Patients are very nervous, with an increased sensitivity (perception) to pain *(Moulton, 1957)*. Facial pain is a frequent complication of menopause, being associated with life upheavals. These patients frequently report a physical traumatic precipitating factor, such as an extraction, restoration, fall, etc. There will be strong hostility and anger which is directed toward the dentist. Behavior will alternate between dependent pleading and excessive anger for lack of cure. Lawsuits may result and nonpayment is common.

Pain in the tongue and palate is common. Various abnormal sensations may be present such as paresthesia, burning, itching, stinging, and dryness. The most common type of patient is post-menopausal, unduly disturbed over oral conditions, nervousness, depression, insomnia, and cancer phobia. The pain is usually persistant but bearable (able to sleep and carry on usual activities). Estrogen therapy has not been successful. Placebos provide immediate but transient improvement for several days or a week. Psychiatric counseling provided fairly good results *(Ziskin and Moulton, 1946)*. Reassurance about the tissue health and offers of periodic evaluation are reassuring.

Discussions of the relation of habits and tension is helpful. A thoughtful but very cautious dental approach is in order. Dental care is provided slowly in a relaxing, nontraumatic manner. Complex and radical treatment is not recommended since these patients can become "addicted" to physical procedures to relieve anxiety. These patients do not want psychiatric help, but seek dental help. A rational and understanding dental approach is needed. The patient should be encouraged to bear with minor discomforts and not hope for unrealistic improvements. It is important not to discuss the specific psychological mechanisms involved. Patients are not prepared to receive this information, nor is the dentist prepared to provide it *(Moulton, 1957)*. Conservatism and reassurance are the rules in treatment.

**TEMPOROMANDIBULAR JOINT DYSFUNCTION.** Disturbances of the temporomandibular joint are a specific type of facial pain. Many of these patients show similar characteristics to those with other types



of facial pain. The problem is complicated by the physical factor of the occlusion of the teeth as a contributory factor. Correction of malocclusion may result in some remission, but the common findings of emotional factors must be considered for long-term relief *(Kydd, 1959)*.

Joint disorders present a baffling diagnostic problem to the dentist. Most patients have significant malocclusion as well as the presence of strong psychogenic factors *(Shore, 1962)*. Since numerous factors are involved, reduction of any one may bring some relief.

Investigations have shown emotional disturbance in the majority of patients *(McCall, et. al., 1960; Kydd, 1959; Moulton, 1955; and Brody and Nesbitt, 1967)*. Various tests were employed including: Minnesota Multiphasic Personality Inventory, Cornell Medical Index, Edwards Personality Profile, psychiatric interviews, and careful occlusal analysis. The emotional factors were found to play a significant role in face-mouth-teeth problems. "Body language" is observed in "gnashing of teeth" or a jaw "set in determination." Anxiety symptoms involve the autonomic nervous system (i.e., palpitation, syncope, weakness, nausea, diarrhea, and immobilization), while striated muscles may show a paralysis resulting from flaccidity or spasticity *(Moulton, 1966)*.

The treatments of temporomandibular joint pain are numerous. Emphasis is placed on various parts of the etiology, treating the occlusal disharmony or the emotional problem, or by treating the symptoms of muscle spasm, pain, or malocclusion. The fact that many treatments apparently are successful emphasizes the emotional overlay. Treatment must consider psychogenic factors in order to succeed. The human factors play a significant role in this disease *(Brody and Nesbitt, 1967)*.

**PERIODONTAL DISEASE.** The correlation of emotional factors and periodontal disease has been known for many years. Studies in the United States Army during World War II were able to relate stress and fatigue to the incidence of gingival inflammatory disease *(Schluger, 1949)*. It has been postulated that this represents somatic change due to emotional reactions through the mechanism of vascular changes *(Mellars and Herms, 1946)*. Acute necrotizing ulcerative gingivitis provides a good model to observe the relationship of emotional factors and disease and to study psychophysiologic disorders of the oral cavity *(Giddon, 1966)*.

There are a number of ways in which mental well-being can be related to the integrity of oral tissues and interfere with periodontal health *(Miller and Firestone, 1947)*; **a.** reduction of local nutrition (vasospasm), **b.** objective habits (biting nails, fingers, pencils), **c.** excessive chewing, clenching, and grinding, **d.** taste perversions resulting in poor dietary habits (high carbohydrate, low protein), **e.** insufficient food intake, **f.** neglect of oral hygiene, **g.** subjective habits (tongue thrust, tooth tapping, lip biting), and **h.** cause body functions which are poor for periodontal health (blood calcium level).

Periodontal disease is caused by a complex relationship of local and systemic factors. While emotional etiologic factors are well accepted in some clinical syndromes (ulcers, colitis), there has been less agreement concerning their role in periodontal disease (other than gingival inflammation). Causitive mechanisms have been discussed and classified *(Moulton and Thieman, 1952)*. Direct causes (overt habits) involve oral hygiene, diet, oral habits, and bruxism. Indirect causes (emotional conflicts and involuntary physiological mechanisms) include endocrine dysfunction, resistance to infection, circulation disturbances (depression-blue and cold, manic-flushed, anxiety-palpitation, and salivary factors-flow and acidity levels). Subjects tested showed common characteristics of oral dependency, anxiety, conflict, and bruxism.

Controlled testing of periodontal patients with psychological tests (Minnesota Multiphasic Personality Inventory) showed a correlation between emotional factors and caries, DMF rate, and periodontal disease *(Manhold, 1962)*. The relation of anxiety and periodontal problems was demonstrated.

The psychosomatic role of human factors in dental disease has gained acceptance during recent years. Nonspecific stress can result in problems of bruxism, salivary changes, nutrition changes, and resistance to infection *(Manhold, 1962)*.

## EFFECT OF TOOTH LOSS

The transition from natural to artificial dentition requires considerable adjustment on the part of the patient. There will be changes in appearance, mastication, and speech for varying periods of time. This necessitates a change in life style and body image for an interim period. Healthy patients who adapt well are able to adjust and accept the limitations of appliances.

The anticipated loss of teeth causes great concern. Patients may be angry with themselves for neglecting their dental needs and resent the fact that the teeth will be lost. This results in anxiety and discomfort for the patient. In order to relieve this anxiety, these feelings are transferred to someone else by projection. Parents or previous dentists are blamed for the tooth loss and this protects the patient from inner dissatisfaction *(Hart, 1948)*.

The response of the patient to tooth loss may be exaggerated and inappropriate *(Sosnow, 1962)*. Appointments may be frequently broken or the treatment may be totally rejected. Exaggerated fears may be expressed in unusual reactions such as sweating, gripping the chair arms, vocal sounds, etc. Statements are made about extractions which are not commensurate with the procedure, such as "I would rather have a baby than a tooth extracted." Reassurance about the replacement reduces concern that it is a nonproductive loss. Methods of replacement are important in reassuring the patient *(Passamonti, 1964)* and will be discussed later in this review.



Patient behavior is modified by fear. The patient does not consciously or voluntarily wish to be difficult but appears unable to help himself *(Epstein, 1962)*. Anxiety is easier to prevent than control. Anxiety occurs because of anticipated changes in the total personality *(Landa, 1953)* when body parts are to be lost *(Moulton, 1946)*. It is important for the dentist to understand the significance of tooth loss to the particular patient *(Swoope, 1969)*. The loss of teeth may be symbolic of age, senescence, and death *(Kimball, 1960)*. It is not surprising that the response to this symbolization is highly emotional. The denture may be looked upon as a penalty for growing old, with the impact of impending extraction resulting in depression *(Ferber, 1963)*. The tooth loss is viewed as causing wrinkles and facial sagging characteristic of old age *(Young, 1954)*.

The loss of teeth appears to vary with age and socio-economic factors, such as income, education, etc. *(U.S. Public Health Service, 1960)*. When the loss of teeth is partial, occlusal problems may exist which contribute to joint dysfunction *(Shore, 1963)*. Retaining the teeth may be viewed as retarding the aging process *(Lefer, 1971)*, and bad news about the teeth emphasizes to the patient that he is growing old *(Sinick, 1964)*. Elderly patients have a reduced capacity for motor learning, tend to be depressed, and have physiologic changes such as change in salivary rate *(Vinton, 1964)*. There is a constant interaction of chronologic age, physiologic age, and psychologic age.

There is sometimes a paradoxical response to surgery where the patient scheduled for minor procedures is very apprehensive and the patient scheduled for a very large and serious operation may show little conscious fear *(Deutsch, 1942)*. It is more common for patients facing extractions to have fear. There is no outlet for this fear in a dental situation and anxiety results *(Sinick, 1964)*.

The patient with emotional problems frequently shows an exaggerated gag reflex. This may be a type of hysteria reaction to the impending loss of teeth or change in appearance. The dentist faces a very difficult task in the management of a patient with gagging problems of psychogenic etiology. There is also an organic etiology which appears to result from a low threshold for the nerves involved in the reflex. The sensory innervation involves the trigeminal, glossopharyngeal, and vagus nerves. The cranial motor nerves are the trigeminal, facial, glossopharyngeal, vagus, and bulbar portion of the accessory *(Blashki, et al., 1949)*. The reflex is a natural one but it becomes greatly enhanced by psychogenic factors. A patient may exhibit apprehension and anxiety during examination and make statements that he cannot tolerate anything in his mouth.

There are a number of factors which will aid in management of gagging. Impression procedures are critical *(Borkin, 1959)*. Errors in vertical dimension can result in problems *(Schole, 1959; Krol, 1963)*. Distraction and suggestion are helpful *(Means and Flenniken, 1970)*. When appliances are delivered, the patient should be allowed to develop some confidence before leaving the office *(Landa, 1958)*.

Efforts should be made to determine the etiology of gagging so that management can be planned in advance. Confidence of the dentist is a significant factor since patients sense this confidence and are reassured. Training appliances and exercises may be employed, and generally a combination of techniques are utilized. Success occurs as the patient develops a positive attitude toward the appliance and confidence in a successful outcome.

Changes in speech occur during the transition from natural to artificial dentitions. The time required for normal speech to return varies with each patient *(Troffer and Beder, 1961)*. Faulty speech with new dentures causes embarrassment for the patient and adds to his burden of physiologic adjustment *(Allen, 1958)*. Fortunately, normal speech usually returns in a few days to a few weeks. The speech mechanism is quite adaptable and usually adjusts readily to contour changes. Careful attention to palatal contour and the effects of irregular tooth patterns will reduce the problem *(Rothman, 1961)*. Phonetics rarely appears to be a problem if esthetic and mechanical problems are met.

Masticatory efficiency obviously will be impaired with the change to artificial dentition *(Yurkstas, 1954)*. The force exerted by appliances is considerably less than the natural dentition. However, with careful cooking and preparation there can be a 75 percent reduction both in the amount and force of mastication required prior to swallowing *(Yurkstas and Curby, 1953)*. Careful preparation of the patient will be discussed in a later section. It is obvious that patient instruction in the care and use of dentures is required.

Many responses to the loss of teeth are observed. These appear to occur because of the association with other life changes such as growing old, loss of reproduction, facial changes, hair changes, decreased earning capacity, and general decrease in worth as an individual *(Swoope, 1969)*. The patient also reacts to the dentist, the procedure, and the completed restoration *(Miller, 1970)*.

Empathy on the part of the dentist will help the patient to adjust to the impact of tooth loss. Emotional support, an opportunity to express feelings, discussions of dental problems and what can be done, all help the patient look to dentures with a positive attitude and decreased fear and anxiety.



## THE THERAPIST (DENTIST)

The relationship between the dentist and the patient is crucial to the success of any treatment plan. There must be a mutual feeling of respect and confidence. If there is a personality clash, then the differences should be resolved or treatment terminated. Another dentist might provide a more compatible and comfortable relationship.

The need for complete dentures is very disturbing to a patient. Successful conclusion depends on development of any early positive interpersonal relationship *(Sharry, 1968)*. The dentist must develop himself and broaden his art *(Wilson, 1920)*. Any intelligent dentist can apply sound counseling techniques. Psychiatry is not for just a few specialized physicians *(Crane, 1970)*. Dental patients need sympathetic counsel and verbal advice, not necessarily chemical tranquilizers. The interactive nature of the dentist-patient relationship is complex because of the complexity of perception *(Borland, 1963)*. The process of communication is prone to errors, distortions, and omissions. Personality clashes will arise and must be resolved *(Lefer, et al., 1962)*.

The teeth represent a body part which is important to all social situations and relations. They symbolize a person's character, values, life style, and socio-economic class. Patient attitudes toward dental care involves these interpersonal factors. The dentist is viewed primarily to treat disease or correct cosmetic factors, not for prevention *(A.D.A. Bureau of Economic Research and Statistics, 1958)*. The patient, therefore, is usually in trouble when he visits the dentist. The dentist is expected to be all things to the patient. Pain in the face is especially resented and the body is threatened causing fear and anxiety *(Gillin, 1961)*. Hostility may be expressed by nonpayment or attacks on the integrity of the dentist.

When patients exhibit anxiety, the dentist may also feel anxious and may become irritated, angry, over-solicitous, or over-sympathetic *(Steiger, 1967)*. It is the person, not the disease, which interferes with the logical management of the problem. The therapist should not respond with multiple tests or just ignore the patient's behavior, but should encourage the patient to talk. The dentist should be relatively passive (not verbally "dissect" the patient) and observe how the patient handles interpersonal relationships. There is a need for increased self-awareness of the dentist in the ways patient behavior affects their own behavior, and how their behavior affects patient feelings and symptoms *(Borland, 1962; Steiger, 1967; Kaplan, 1958)*. If the dentist is fatigued, unhappy, or depressed he will respond to tension with increased tension in himself and react to patients with irritation, anger, withdrawal, or over-treatment. When the dentist is brusque, hurried, or dogmatic, communication decreases and patient fear increases *(Moulton, 1946)*.

While the patient may expect the dentist to be "all things," he actually must carry out procedures which cause discomfort. His role is not to resolve conflicts like the psychiatrist, but to treat dental disease *(Friend, 1953)*. While psychological training is necessary for the dentist, and consideration of human factors is important, he is not responsible for the total behavior of the patient. Dentists enter the profession for various reasons, such as prestige, earnings, human service, autonomy, and manual skill *(Moore and Kohn, 1960)*. Independence was a strong factor in choosing dentistry with a desire for flexibility in determining life style. The dentist does have persona' feelings and hostility or nonpayment by patients causes tension. The dentist must then increase fees or production to compensate for this patient and these alternatives cause problems. The dentist actually has little time for family and diversionary activities, even though this was a primary objective for entering the profession *(Gitlin, 1961)*.

The dentist must carefully view himself and work to improve dentist-patient relations. Good "bedside manner" and interpersonal relations can be developed through the use of positive reactions and good dentist attitude *(Kaplan, 1958)*. The dentist must, however, recognize his own limitations. When personality conflicts cannot be resolved, the patient should be referred elsewhere. There are also instances where the dentist has inadequate personal skill to manage the patient's problems. While this is hard on the ego of the dentist, referral is in the best interests of both *(Koper, 1964)*.

Most patients in a prosthodontic practice are elderly. They have special problems such as degenerative changes, poor reaction to stress, poor health, and social factors such as boredom and loneliness. The dentist must take time to talk at length with his patients—before, during, and after treatment. Patients respond positively to those who like them and the dentist should be sure of his own responses *(Sharry, 1968)*. Success for the patient will depend on physical fitness, understanding of the problems, and confidence in the dentist. The dentist must make a positive effort to increase his capacity to increase confidence and communication.

Aging persons adjust gradually through the years to the handicaps of senescence by decreasing activities to a level compatible with his own appreciation of the functional reserve available to him *(Landa, 1957)*. The total personality of the patient must be treated with sympathetic understanding. Continual self-appraisal is required of the conscientious dental practitioner. He must be constantly aware of the effect of his personality upon patients and of his response to patient behavior.

## PATIENT REACTION TO STRESS

In our culture considerable stress and tension is applied to the individual. This fact is not necessarily detrimental since some stress usually precedes accomplishment. It becomes a problem when the person is unable to relieve the stress by actions. The general adaptation syndrome occurs when the internal organs help a person adjust to the constant changes which occur around and in him. The stress syndrome is primarily physiological, its purpose being to protect. Stress stimulates mental development. Faulty response, over stimulation, or prolonged stress can produce disease. The stress rate, which can be defined as the rate of wear and tear on the body caused by life, can increase to a rate that is detrimental and disease-producing *(Selye, 1956)*. The relationship between emotion and disease is stress. The disease results from excessive anxiety, fear, and worry.



There is a complex relationship of human factors, stress, and physical factors. The stress factor is always present. It is a challenge to growth and not always bad *(Moulton, 1958)*. Patient problems increase stress and should not be ignored. Pain is not imaginary and the dentist should not ignore or deny its reality by saying, "don't let it bother you." The capacity to adjust to stress is related to motivation. Learning represents a sequence of behavior patterns to overcome obstructions and resolve conflicts *(Silverman, 1961)*.

It is necessary to apply some concepts of psychiatry in dentistry. The dentist must recognize the status of the patient's personality and evaluate his motivation for care. This infers a behavioral pattern, but not a specific diagnosis *(Silverman, 1961; Kimball, 1960)*. The problem of stress is then faced together with the patient. The existence of stress is recognized and reassurance is provided. Treatment of stress-related problems is kept simple to prevent causing a new focus. The dentist-patient relationship is central in the treatment, with trust as necessary as good anesthesia *(Moulton, 1958)*.

Psychic stress or emotional tension can increase basic muscle activity (tonus). Increased muscle activity may in turn lead to pain in the temporomandibular joint and muscles of the head and neck. The adaptive capacity of the patient is related to his psychic stress. People under severe tension need only minor malocclusion to initiate muscle spasm *(Ramfjord and Ash, 1971)*. Other observers were unable to demonstrate increased muscle activity when relaxed, but found emotional disturbance in most patients *(Kydd, 1959)*. Emotional stress may be induced by physical illness. Emotionally tense people are then predisposed to muscle spasm *(Shore, 1959)*. Temporomandibular joint problems and bruxism appear to need a physiologic problem and an emotional overlay *(Cinotti and Grieder, 1964)*. Patients under stress are generally not desirous of dental care since the dental visit in itself is anxiety-producing *(Kimball, 1960)*. Their dental problems eventually provide motivation to seek care (motivation is the force determining behavior) *(Cinotti and Grieder, 1964)*. The presence of ill health and production of nervousness and stress is important *(Kimball, 1954)*.

Pain is particularly difficult to deal with. It cannot be classified only by pathologic change *(Walker, 1945)*. Medications and surgical treatment are not usually adequate to manage facial pain. Anxiety and frustration result in symptoms being somatized to the mouth *(Heaver, 1947).*

An emotional crisis can produce symptoms in the circulatory, respiratory, digestive, and excretory systems *(Silverman, 1958).* Ordinarily, the parasympathetic component keeps the individual in a state of equilibrium. If the stress is prolonged, disorders occur in the circulatory, respiratory, and gastrointestinal systems which will affect prosthodontic treatment. Some symptoms may result in eventual damage to tissues (habits) while others do not cause actual tissue damage (pain, paresthesia) *(Moulton, 1955).*

Geriatric patients have special problems in their ability to handle stress *(Kimball, 1966).* There are many vague aches and pains with no specific disease connection. The young would ignore these things, but the old suffer. The relationship of physiologic age to chronologic age is important to consider. Older people have difficulty getting along with themselves, other people, and their environment *(Bortz, 1958).* The anxiety of elderly people has an effect on the gastrointestinal system, beginning with the oral cavity. The inability to masticate adequately is a contributing factor and may be focused upon to represent all of the gastrointestinal disturbances present.

Anxiety production related to dental procedures has been studied. Stress was applied by viewing a videotape of an alloy preparation and insertion of a restoration (sound used). There was a wide variety of response *(Corah and Pantera, 1948).* In view of the diverse anxiety responses, some evaluation of the patient is required prior to a final decision on a treatment plan. The dentist needs to explore practical devices to help him evaluate patient stress and anxiety. The Cornell Medical Index is a very helpful tool to aid in this determination *(Brodman, et al., 1951; Bolender, Swoope and Smith, 1969).*

The continual presence of stress is not necessarily harmful. It may be productive in stimulating achievement. When prolonged, without relief, it can initiate disease. As a contributing factor, it can greatly modify patient response to dental procedures. The dentist must carefully evaluate the patient in order to plan treatment and arrive at a valid prognosis.

## COMMUNICATION WITH THE PATIENT

It is important to provide adequate information to the patient. When patients are well-informed, their anxiety decreases. They have less pain, less emotional disturbance, and greater confidence in the operator *(Sinick, 1964).* It is important not to distort the communication by technical jargon *(Plainfield, 1962).* It has been suggested that patient education should include the following: reassurance (not cancer, etc.), ventilation (allow patient to verbalize), re-education (correct misconceptions), suggestion (use nonverbal cues since placebos are of limited value), and interpretation (do not try and interpret specific psychological mechanisms) *(Levine, 1942).*



Communication will help prevent over-reaction on the part of the patient by answering fears honestly and directly *(Moulton,1958).* An effective education program is necessary for successful treatment *(Bliss, 1960).* The dentist should discuss what is anticipated. This will prevent the patient over-reacting to any unexpected procedures *(Binger, 1946).* There are many channels of communication *(Meares, 1963).* Logical verbal communication is the most common. This occurs in patient interviews and history taking. Verbal communication is not always straightforward. Extraverbal communication may include innuendos and the dentist must "read between the lines" *(Koper, 1970).* A question about how the patient is doing might be answered by, "Oh, all right," which could mean anything depending on other forms of expression which accompany it. Unverbalized phonation would include expressions like "ummm" or "ahh." These may modify the logical meaning of the adjacent verbalization. Facial expression, gesture, or posture can convey or modify meanings. A raised eyebrow or shrug can express a different meaning from what is actually spoken. Behavior such as role-playing, transference, or touching the person is meaningful. There may be unconscious communication through attitude, mood, and psychological defense mechanisms.

The dentist must spend much time gaining confidence and teaching patients *(Piraro, 1963).* It is important that our education and communication be effective and efficient. Effective communication must be established at the first visit. The patient and the dentist evaluate each other and, in the presence of good communication, will develop trust. Nonverbal factors such as expressions, voice tones, gestures, posture, sweating, tremors, as well as extraverbal innuendos must be considered *(Koper, 1970).* Patients who are unreasonable are unable to communicate effectively and tend to retain unreasonable expectations and beliefs *(Blum, 1960).*

Communication may be in the form of written reports, letters, or resumes *(Koper, 1964; Swoope, 1970).* This prevents misunderstanding about what was desired or requested, what was possible, and what was accomplished. Many misunderstandings develop concerning fees and what treatment is included in the fee. It is helpful for this information to be written *(Swoope, 1970; Friend, 1953; Blum, 1960).* This topic will be discussed further in another section of the review.

The use of intermediate appliances will communicate to the patient that he has the capacity to adapt to an appliance and confidence in his ability to utilize it effectively *(Pound, 1962).* Patient instructions are very important *(Klein, et al., 1969).* They may be verbal or written. Written information is available in pamphlets and books *(Your New Dentures, 1971; Hall, 1969).*

Effective communication requires that the patient actually hears and understands what the dentist says. The verbalization must be in simple terms so there can be no misunderstanding *(Bliss, 1960; Plainfield, 1962; Sinick,* 1964). The approach should be; **a.** to relieve fear and anxiety, **b.** communicate in nontechnical terms, **c.** always make some positive comments about the mouth, and **d.** do not sympathize and focus on the pathology but have empathy for the fears, discomfort, and concerns *(Plainfield, 1962).*

## IDENTIFICATION OF POTENTIAL PROBLEMS

It is essential to identify potential problems before making a commitment to a definite plan of treatment or fee determination. It is a serious error to proceed with treatment after only a cursory clinical examination. There are a number of useful clinical tests which can help identify potential difficulties. Dentures may fail for a variety of reasons *(Koper, 1964).* There can be failure because of inadequate patient evaluation. This could be a failure to recognize physical limitations such as structural (resorption), systemic (tissue health), neuromuscular (coordination), or post-surgical and radiation sequelae. There can also be a failure to recognize the psychological limitations imposed by the patient which might be manifested by salivation, gagging, pain, clenching, etc. It is important to recognize our own limitations. There can be personality conflicts which should be referred elsewhere or insufficient professional skill to manage the technical problems. Failure to prepare the patient can result in rejection. Physical preparation by means of tissue conditioning, surgery, etc. is self-evident. Emotional preparation to reassure, perceive wishes, and limit expectations is more subtle. Technical errors in construction can result in failure and the dentist should check carefully to insure none are present. Consultation can be helpful during planning stages and dentists should make more use of their colleagues in this context. After-care is very important and inadequate follow-up can cause failure *(Koper, 1964).* With the causes for failure defined, attention can be given to specific identification of potential problems, not past problems. The way for successful management to begin is with identification of anticipated difficulties before treatment starts, and careful planning to meet specific needs and problems of the individual patient.

The interview and clinical examination is the obvious way to observe patients and classify them with regard to potential problems with denture function. It is not easy to use interviews effectively and efficiently. Dentists are reluctant to ask probing emotional questions so little useful information is obtained about patient attitudes and feelings. The dentist must train himself to become competent in interpersonal relationships and form the best treatment relationship *(Bloomfield, 1962).* The interview will include history-taking. Why is the patient in your office? Is it because he recently moved to town or because of dissatisfaction with the previous dentist? Has he had one denture for twenty-five years, or six dentures in the



last five years? At the first meeting, the patient and the dentist appraise each other. The dentist needs to find out what the patient wants and whether he is prepared and willing to treat him. The patient needs to find out if the dentist can satisfy his needs *(Koper, 1970).* The dentist is interested in the patient as a person as well as a good description of the symptoms. He is aware of patient emotions as well as obtaining an accurate picture of the complaint. The relationship of the symptoms and tensions must be explored *(Moulton, 1959).* Temporal correlations of symptoms and life crises, as well as the role of symptoms in the life pattern, must be explored. Do the symptoms incapacitate, is there stoic indifference, or are they used to avoid anxiety-producing situations? The way in which patients handle other illnesses and dental situations will aid in prediction of future problems. The secure person will adjust readily, put up with discomfort, and be cooperative *(Moulton, 1946).*

There are ways to make interviews and histories more effective and efficient. It is important to obtain maximum information with minimum chair time. The use of health questionnaires is helpful. The Cornell Medical Index has been shown to be efficient and accurate *((Brodman, et al., 1951).* It rapidly gathers a large body of comprehensive information on the physical and emotional status of the patient. The questions have been carefully tested and shorter groups of questions found to be inadequate *(Brodman, et al., 1952a).* Estimates by admitting physicians of emotional disturbances in hospital populations were 10 percent. The Cornell Medical Index revealed many additional significant disturbances which were important to full understanding of patient disorders *(Brodman, et al., 1952b).* It is easily reviewed since only "yes" answers are reviewed. Areas are not overlooked due to time and hurry. The questionnaire indicates areas to be pursued. The interview is facilitated and productive *(Brodman, et al., 1949).* The Cornell Medical Index has been extensively used and investigated in a dental institution. Experience of eight years has proven it to be effective in gathering information to aid in interviews. It also is an effective prognostic device with critical levels of responses which can be correlated with denture satisfaction *(Bolender, Swoope and Smith, 1969).*

Successful diagnosis depends on thorough examination and correct diagnosis. An intelligent prognosis can then be based on this knowledge *(Kingery, 1936).* The dentist must be certain he can improve things or should not begin treatment. The whole patient must be evaluated and the golden rule applied, that is, treat as you would like to be treated *(Brewer, 1964).* Complicating factors have an additive effect on a poor prognosis. These factors include general debilitation, abnormal jaw function, abnormal jaw relationships, redundant tissue, and poor attitude. Mental attitude must be evaluated in terms of how the patient will adjust to something new, or how easily he will be discouraged *(Appleby and Ludwig, 1970).*

There are particular problems related to the elderly and the presence of advanced age allows prediction of some problems. They usually seek care because the esthetics of an old appliance is no longer acceptable or the material has begun to disintegrate *(Stout, 1964)*. It is an error to be overconfident because they have worn appliances for many years. There are mucosal and systemic changes, and they do not adapt readily. The reduced capacity for motor learning (coordination) may be accompanied by depression *(Vinton, 1964)*. Aging changes may be metabolic, psychosomatic, and neurogenic as well as oral. They age both emotionally and physically at different rates *(Heartwell, 1970)*. Nutrition problems are important from the standpoint of preparation (mastication) and digestion *(Ryan, 1951)*.

One of the most important treatment modalities is understanding the patient. The final result is enhanced or jeopardized dependent on the ability of the dentist to utilize the available information. Failures are minimized by understanding the physical and psychological character of the patient *(Jamieson, 1960)*.

In order to identify problems the dentist must find out; **a.** the desires for or dissatisfaction with dentures, **b.** health and living status and patterns, **c.** condition of oral and perioral structures, and **d.** adequacy of the dentures presently being worn *(Koper, 1970)*. The clinical examination will determine the adequacy of the existing appliances. Large deficiencies are easily observed. Small deficiencies probably do not change the degree of success. The condition of the tissues is meaningful. With this information, what is desired can be related to what is possible.

## PREPARATION OF THE PATIENT

Preparation of the denture patient should be physical and emotional. The total patient is carefully evaluated to determine limitations and deficiencies. Correction of physical problems is made prior to denture construction. These include items such as; **a.** surgical correction of the ridges, **b.** tuberosity reduction, **c.** vestibular extension, **d.** tissue conditioning, etc. The use of tissue conditioners to return the tissue to optimum health is important *(Lytle, 1957)*. In order to succeed, the preparation must be psychologic, physiologic, and economic *(Boos, 1957)*.

The emotional preparation of the patient is less clearly defined. It begins at the initial interview and continues into the post-insertion phase. Early in treatment, emotional preparation consists of increasing patient motivation. Those who are not motivated do not seek care, so some degree of motivation is already present. This means the patient realizes a deficiency exists and the need for improvement *(Collett, 1967)*. A limitation of denture function is the ability of a patient to learn to adapt to a denture and to master the efficiency built into them *(Pound, 1962)*. Preparation in this instance means a mutual understanding of the problems.



The section on tooth loss and body image dealt with the impact of dentures on the patient. It has been suggested that most psychological-dental information in the literature is not very helpful. It is either too complex (with psychiatric terminology and conceptual schemes), or oversimplified (i.e., use "common sense" or "size up" the patient and his needs) *(Nagle and Sears, 1962)*. Motivation will result in purposeful behavior to seek out care for various reasons; **a.** relief of pain, **b.** prevention of pain, **c.** maintenance of health, and **d.** maintenance and development of appearance.

Preparation includes patient education. It has been suggested that examination procedures involve three phases; evaluate, educate, and estimate *(Pound, 1963)*. Education is achieved in a variety of ways. Since the communication process is complex and prone to errors, misunderstandings will occur *(Borland, 1963)*. Education depends on a favorable relationship at the beginning of treatment. Communication may include the use of books, pamphlets *(Hall, 1969)*, letters, and reports *(Koper, 1964; Swoope, 1970)*. Education is a continuous thing with need for sympathetic understanding *(Bliss, 1960)*.

The try-in appointment is critical in the preparation of the patient. This is a final check-point for vertical dimension, occlusion, and appearance. The patient and dentist must be satisfied with the results. The joint venture is emphasized by participation of the patient *(Koper, 1964)*. A family member or friend should be encouraged to be present to furnish input *(Payne, 1960)*. Written statements of various types are used to identify changes needed or signify approval. When any hesitation exists about appearance, the waxed dentures are sent home on approval *(Swoope, 1970)*. Esthetics are a primary factor in the success of an appliance *(Fisher, 1957)*. Every effort should be made at the try-in to prepare the patient for the appearance of the completed denture.

Preparation at the initial interview begins by reassurance to calm fears, followed by re-education of misconceptions *(Levine, 1942)*. Communication results in patient awareness of the problems *(Borland, 1953)*. Patients need to be realistic in their expectations *(Woods, 1964)*. We need the mental assistance of good denture esthetics to help solve the problems which occur with all well-made dentures. It is difficult for the dentist to assess the attitudes of the patient, so there must be enough time to talk at length before, during, and after treatment *(Sharry, 1968)*.

Since denture-wearing is elective, and not wholly comfortable, it represents something to become adjusted to in terms of patient annoyance *(Moulton, 1946)*. We need to have empathy for the patient, as well as possess physical skills. These patients have many problems, such as decreased muscle tone and coordination, inability to manipulate appliances, thin and tender mucosa, slow recovery from injury, less vigor, fatigue, decreased taste, etc. *(Epstein, 1966)*. A line from Shakespeare's "As You Like

It" can be modified to read, "sans teeth, sans eyes, sans taste, sans everything."

Since preparation in the context of patient education takes place in the office, the office itself is important. This is the atmosphere in which trust and mutual respect grow and good communication are established, or hostility and misunderstanding can flourish *(Moulton, 1959)*. A favorable environment includes; **a.** an office which is clean, in good taste, and cheerful, **b.** conducive to the feeling of relaxation, **c.** has pleasant surroundings and a sympathetic approach (including office staff), and **d.** shows consideration of complaints and fears *(Oman, 1955)*. The use of relaxation and suggestion can be employed to reduce anxiety and fear, and place the patient in a receptive frame of mind *(Jarabak, 1953)*. The office staff and office itself aid in communication and preparation.

The goal of the prosthodontist is patient happiness. We should condition the patient to problems ahead and maintain their morale and confidence *(Pound, 1954)*. Education involves a variety of approaches, including written patient material *(Shore, 1970)*. The effect of tooth loss must be predicted so the patient can be prepared *(Weiss, 1944)*. The patient must accept some physical decline, but we must insure the least trauma possible *(Epstein, 1966)*.

## METHODS OF TOOTH REPLACEMENT

The manner in which teeth are replaced is very important to the patient. Reassurance that they will have minimal disruption of their usual activities is a great comfort. Not all patients are in a proper frame of mind to be treated. They are reacting to the loss of a body part and need a mental adaptation to the prosthesis *(Passamonti, 1964)*. The response of a patient to anticipated tooth loss will influence the treatment plan *(Swoope, 1969)*. Decisions may have to be made between overdentures, periodontal-splinting procedures, or removable partial dentures. The feelings of the patient must be communicated and understood in order to plan a course of treatment which has some chance of actually being performed.

In some instances, the change to artificial dentures can be made in stages. The initial decision between removable partial dentures and complete dentures will be made partly on bone factors. "Index areas" where the bone is under stress is evaluated *(Applegate, 1957)*. If the response of the supporting structures around a partial denture is good, the prognosis for continued function is good. If the periodontal structures in an intact arch are deteriorating, their prognosis as abutments is poor.

Very few people who need dentures want them *(DeVan, 1958)*. The use of partial dentures as an interim measure can be helpful psychologically. Temporary partial dentures can be used to "educate" the tissues, coordination, and tolerance of the patient *(Pound, 1970)*. The patient is entering a new phase of his life with varying degrees of fear and trepidation. When there is no previous experience with dental appliances, the life change is easier to accept in degrees. The interim dentures are used until everything is satisfactory, then treatment can progress. The interim partial dentures can be converted to interim complete dentures. When healing changes are completed, and the patient is again satisfied, terminal management of new dentures is begun *(Pound, 1970)*.



When complete dentures are indicated, the changes to be imposed on the patient are evaluated. Health and socio-economic factors are considered as well as the "dental intelligence quotient." Tooth removal for economics alone is usually not justified *(Trapozzano, 1960)*. Requirements of artificial dentition are different from natural dentition. These changed requirements may necessitate a change in occlusal configuration, tooth position, or esthetics. Requirements of artificial dentition include; **a.** stability in centric relation, **b.** balanced occlusion, **c.** unlocking of cusps mesio-distal (to accommodate settling), **d.** control of horizontal force by buccal-lingual cusp reduction (depending on residual ridge size and interarch space), **e.** functional balance by favorable tooth-to-ridge relation, **f.** cutting and shearing efficiency, **g.** anterior clearance during mastication, and **h.** minimal occlusal area for reduction of pressure during function. Patient instructions are required, such as: not to eat beyond the capacity of the ridge, rest the tissues, chew bilaterally, and eat foods high in protein and low in carbohydrates *(Ortman, 1971)*.

When dentures are to be made, immediate dentures are usually indicated. Many benefits can be gained by never having the patient completely edentulous. Advantages of immediate dentures are said to include avoidance of undesirable muscle function habits (lack of precise jaw position, tongue using excessive space, speech changes, etc.), protection of extraction wounds, splint-like action to control hemorrhage and mold the ridge, to maintain normal appearance, speech, and mastication *(Laird, 1970)*. Mental comfort by not being without anterior teeth cannot be over-emphasized.

Usually the roots of several teeth can be retained to help support the denture. This has a number of advantages *(Lord and Teel, 1969)*. The residual ridge is shielded against masticatory stress, the vertical height of the residual ridge is preserved, denture stability is increased, and the patient does not view himself as edentulous *(Lord and Teel, 1971)*. There are various techniques for using retained roots, and they are readily incorporated into immediate denture procedures *(Morrow, et al., 1969)*.

The use of a "near immediate" denture has been suggested *(Landa, 1958)*. This involves utilization of a stent with anterior teeth only. After initial healing, conventional dentures are constructed with the obvious advantages of better impressions, clinical try-in, etc. Alternative techniques involve temporary or transitional dentures *(Rayson and Wesley, 1970)*. They are constructed prior to any extractions and duplicate the existing occlusion *(Swoope, et al., 1971)*. Minor changes can be incorporated but generally the esthetics are unchanged. The extractions are performed by arches with immediate replacement. Intermediary relines are utilized during the healing period followed by conventional denture construction.

Reassurance concerning esthetics and speech seem to be central factors in the successful transition from natural to artificial dentition. The preservation of natural tooth position for esthetics and phonetics is important *(Pound, 1951)*. Careful tooth placement, attention to form, and gingival form will be greatly appreciated and ease anxiety *(Frush and Fisher, 1957)*. The importance of esthetics and the use of additional family members or friends for input and approval is necessary *(Hardy, 1960)*. The careful use of pre-extraction records insures retaining correct tooth position and reassures the patient. There are a number of practical clinical methods to obtain adequate pre-extraction records *(Smith, 1971)*.

The manner in which teeth are to be replaced is important in patient adjustment to the difficult transition in dentition. Appearance is usually of the highest priority and assurance that changes will be minimal has a calming effect. Certain esthetic improvements, after agreement on what is desired and possible, can lead to anticipated improvement rather than dread. Many patients adjust very well, are pleased with their dentures, and may remark they should not have waited so long.

## INFLUENCE OF HUMAN FACTORS ON DESIGN OF OCCLUSION

There will be an influence of total patient make-up on the design of occlusion. These patients are primarily elderly and there are usually numerous significant human factors present. There will be problems of age, health, and tolerance *(Stout, 1964)*. Physiologic changes are important and involve decreased taste, reduced secretion, decreased gastrointestinal mobility, central nervous system changes with decreased learning ability, and motor responses *(Vinton, 1964)*. Physiologic changes like these will influence the choice of occlusal pattern. Altered nutritional habit patterns occur and may result in deficiencies which influence tissue health. Patients are easily fatigued and do not adjust well to any coordinated tasks *(Epstein, 1966)* Emotional status can change muscular coordination. Tension and anxiety can impair muscular function and be reflected by inability to follow instructions for jaw movements *(Ramfjord and Ash, 1971)*.

An obvious objective in denture construction is to minimize the loss of alveolar bone. This can be accomplished by; **a.** assuring optimum health prior to making impressions, **b.** avoiding locked occlusion, **c.** careful occlusal adjustment at delivery, **d.** recall regularly to correct occlusal disharmonies, and **e.** keeping the appliances out at night *(Kelsey, 1971)*. There are great differences of opinion in the selection of posterior occlusion. Some authors recommend the use of occlusal designs with steep cuspal inclinations in all instances, even when jaw abnormalities are present *(Schlosser and Gehl, 1953)*. Other authors suggest variations of tooth form depending on the ridge form. In this scheme, steeper cusp forms are used where good ridges are present. Flat cusp forms are used for poor ridges where movement is anticipated *(Payne, 1957)*. Other authors suggest the use of cusp teeth which are unlocked (mesial-to-distal) to accommodate settling *(Ortman, 1971)*. It has been suggested by some writers that flat cusp forms are indicated in most situations. There are exceptions when natural teeth are present, but most patients should be treated with nonanatomic teeth. Flat cusp forms are definitely indicated in; **a.** patients with extensive mandibular ridges, **b.** retrognathic arch relation, **c.** posterior crossbite relationships, and **d.** senile patients *(Bolender and Lord, 1969)*.



Bruxism creates special problems of occlusion for any patient, and these are magnified for the edentulous patient. Clenching habits require special management because of rapid tissue changes, frequent breakage, and endless adjustments. Suggested approaches to treatment include the following; **a.** avoid increasing vertical dimension, **b.** inform the patient of his responsibility, **c.** use metal bases to avoid fractures, and **d.** leave the dentures out at night *(Sheppard, 1964)*. Several specific (occlusal) suggestions include; **a.** develop perfectly balanced occlusion, **b.** narrow posterior tooth from buccal-to-lingual, **c.** close vertical dimension slightly, and **d.** include psychological treatment *(Landa, 1958)*.

Tooth form in relation to denture base deformation has been investigated *(Swoope and Kydd, 1966)*. It appears that cuspal inclination is a more significant factor than occlusal area in base deformation. Since base deformation is an indication of lateral stress applied, it would seem appropriate to keep the occlusal scheme simple and flat in instances of bruxism, poor ridges, poor coordination, and poor adaptation. The patient with flat ridges and poor muscular coordination can hardly be expected to manage precise positional occlusal contact with mastication. It would seem appropriate to provide *areas* of function so that the requirements for precision motor control are reduced. The aging person must adjust by decreasing his activities dependent on the physical resources available to him *(Landa, 1957)*. When decreased capability for mastication results from changes in ridge size, tissue quality, and muscular function, there will be changes required in the occlusion.

Studies indicate that occlusal configuration may not be very important to the patient. In fact, posterior tooth form has been changed without patients being aware of the change. This would indicate that the choice can usually be made by the dentist, based on mechanical factors.

There are two instances when the patient can influence tooth selection.

One situation is where a denture opposes natural dentition. In this case, a posterior tooth form should be selected which is in harmony with the remaining natural teeth. The other instance concerns esthetics. Some flat cusp forms have rather unesthetic maxillary premolars. This can usually be overcome by reshaping the tooth or modifying an anatomic tooth and substituting the premolar. Studies indicate that appearance is of primary importance. Patients tended to choose posterior forms that "looked best" *(Brewer, 1970)*. Some stated that certain tooth forms (Hardy cutter bars) were the most efficient, but then did not choose the dentures with these teeth. Instead, they chose another form which was less efficient but more esthetic. This presents a problem for the dentist who desires flat cusp forms for reasons of force distribution and other physical factors. The patients express obvious desires for pleasing appearance. Careful explanation of the needs and requirements for tooth form, together with reshaping of premolars will usually suffice.

In patients who will adapt poorly to changes, efforts should be made to minimize the change. The fact that the patient functioned well for extended periods does not mean an excellent prognosis for change *(Stout, 1964)*. The problems of age, health, and decreased tolerance may dictate minimal change. As health problems increase, so do problems in adjusting to changes in dentures. Nursing home patients are good examples of the need for conservative treatment. Rebuilding or refitting of existing appliances may be the treatment of choice.

Duplicate dentures can be used to test proposed changes of various types. An existing denture is duplicated and changes made in tooth position, base coverage, or vertical dimension. A trial period will indicate the response to the proposed changes. Nothing has been done to the existing denture which would commit the dentist to further treatment. Another approach is to make a duplicate denture of the waxed denture at the try-in stage. The patient can wear this for a period of time to evaluate the changes. Alterations can still be made in the waxed denture prior to processing.

It is obvious that human factors can influence the determination of posterior occlusion. The physical and emotional make-up of the patient must be considered in selection of posterior tooth form.

## POST-INSERTION ACCEPTANCE

The patient must be carefully prepared for the dentures. Since few who need dentures actually want them *(DeVan, 1958)*, adequate preparation is needed to insure success. Good physical and emotional health will predispose to successful denture treatment *(Neufield, 1964)*. Achievement of a successful conclusion depends on recognizing the limitations of the dentist and patient, and preparation of the patient *(Koper, 1964)*. If the patient is poorly prepared or unrealistic in his expectations, problems will be projected or focused on the dentures *(Hart, 1948)*.



Aging patients, with their special problems will need careful post-insertion care for success. The changes in physiologic and psychologic age result in decreased adaptive capability *(Vinton, 1964)*. The results do not depend solely on how the dentures look and fit. Success also depends on how the patient uses the dentures, how he adapts to discomfort, and how he cooperates *(Moulton, 1946)*. Denture wearing is elective, never completely comfortable, and requires continual adjustment by the patient.

The ability to adjust to dentures and satisfaction with denture functions can be anticipated. Studies indicate that evaluation of patients with health questionnaires can predict potential problems *(Bolender, Swoope and Smith, 1969)*. Patient education about anticipated problems and realistic expectations caused increased satisfaction and acceptance of the dentures. Correlations have been shown between denture satisfaction and the ability to adjust to health problems *(Emerson and Giddon, 1955)*. Effective counseling can greatly increase acceptance. It is important not to create expectations which cannot be met *(Clapp and Tench, 1921)*.

Esthetics appear to be a central factor in acceptance. The patient must be pleased with appearance, and adequate function will not compensate for unsatisfactory appearance. It has been said that older patients should be entitled to please themselves *(Walsh, 1953)*. The patient's body image may be how he visualizes he *will be after*, rather than how he is *before* the treatment starts *(Ament and Ament, 1970)*. Ignoring esthetic values will insure poor acceptance. Teeth generally should be replaced in their original position *((Payne, 1960)*. The teeth should be pleasing, natural, and not attract attention *(Essig, 1937)*. There is great advantage to patient participation in the development of esthetics *(Rosenthal, Pleasure and Lefer, 1964; Swoope, 1970; and Silverman, 1961)*. The patient places great value on appearance and this causes esthetics to be an important determinant of acceptance *(Williams, 1964)*.

Failures can result from the initial interview where patient health and tolerance are evaluated. The success will depend on personal attitude and understanding *(Boucher, 1970)*.

The success of treatment is not accomplished with the completion of dentures. The post-insertion phase is part of the treatment *(Kingery, 1960)*. There are great individual variations in dentures in comfort, stability, and efficiency. Human factors cause great patient differences in coordination, pain tolerance, and general adaptive capability. This phase of treatment cannot be delegated and there are no "trick or easy" techniques. It is a demanding time for the dentist and he must use knowledge, judgment, and honesty to differentiate technical from patient problems. The delivery phase is important and should consist of the following; **a.** pre-examine each denture individually and remind the patient of the prognosis, **b.** check the tissue surface with disclosing paste, **c.** remove the denture with minimal difficulty (don't build challenge in patient's mind), **d.** do not seat the denture with great pressure (retention will not improve), and **e.** explain the speech mechanism and why there will be problems at first *(Kingery, 1960)*.

Post-insertion care is not a remedy; it is the final step in construction *(Woods, 1964)*. Esthetic acceptance has previously been obtained and this provides strong mental support during adjustment. Post-insertion visits should be scheduled at intervals such as two, five, and ten days *(Bolender and Lord, 1969)*. Adequate time should be set aside to make adjustments and listen to the patient's problems. This supportive care is essential. Patients cannot be abandoned after the delivery appointment and then have the problems corrected as they arise. There must be confidence and trust between the patient and dentist which began at the initial appointment *(Koper, 1970)*. Acceptance by the family is essential and must be actively sought by participation and communication.

This phase of care is important to overall success. Appliances which are technically excellent can fail if this phase is ignored. It should be carried through in a spirit of cooperation to reduce problems and produce the best possible result.

## DEVELOPMENTAL AND ACQUIRED DEFECTS

**CLEFT PALATE.** Patients with orofacial defects have many complicating human factors. Physical factors of defects and malaligned body parts create treatment problems. These handicaps can be overcome and do not have to become a social handicap *(Cooper, et al., 1960)*. Without proper care, psychosocial problems will exist *(Spriestersbach, 1961)*. There is a great need for interdisciplinary communication to improve care and reduce the high cost of rehabilitation *(Morris, 1963)*. This area provides an opportunity for cooperation of medicine, dentistry, speech, and many other related disciplines *(Wilk, 1966; Harding, 1963)*.

The physical problems of segments in poor alignment can be reduced. The facial skeleton is not influenced much by therapy, but the teeth and alveolar bone are *(Harvold, 1971)*. Early treatment provides great benefit. Orthodontics can be instituted during the mixed dentition stage *(Warren, 1970)*. This orthodontic treatment can help realign the alveolar processes *(Lewin, 1964)*. Maxillary orthopedics or rapid expansion has been suggested, followed by autogenous rib grafts *(Cronin, 1965)*. The present trend seems to be toward the utilization of more conventional orthodontic procedures, combined with restorative appliances.

When teeth cannot be repositioned conveniently, overlay appliances may be used *(Harkins, Harkins, and Harkins, 1951)*. Initial appliances may be for esthetics and replacement of missing teeth, with obturators added later *(Olin, 1960)*. Lip contour is improved and occlusion is restored using the usual requisites for functional and balanced posterior occlusion *(Cooper, et al., 1960)*. Natural posterior occlusion is poor because of the underdeveloped maxilla. Efforts should be made to balance all occlusal forces *(Malson, 1955)*. Appliances are frequently used when surgical correction is not feasible *(Caruso, 1968)*. Appliances are complicated by bulk and weight, combined with inadequate retention *(Harkins, Harkins, and Harkins, 1960)*. The problem is further complicated in the edentulous patient *(Rahn and Boucher, 1970)*. Every effort should be made to retain some teeth for overlay dentures. If the complete edentulous state exists, there will always be severe problems if an obturator is required. Balanced occlusion and reduction of weight will be of some benefit.



**MAXILLOFACIAL DEFECTS.** Surgical defects of the palate are easier to manage since normal function existed prior to surgery. Temporary surgical appliances are used during the healing period. No teeth are present at this time. Appliances with speech aids and teeth are constructed later *(Aramany and Matalon, 1970)*.

Mandibular defects present special problems. When the mandible is resected, the problems are; **a.** limited coverage and retention, **b.** limited movement of the mandible, and **c.** grossly impaired relations of mandible to maxilla *(Sharry, 1962)*. Satisfactory occlusion is difficult to obtain. The surgical side should not receive occlusal forces and the untreated side is difficult to orient. A team approach is required and the occlusion should be carefully analyzed *(Adisman, 1966)*. When teeth are present, the problem is easier. Appliances can be used to maintain fragments in adequate occlusal relationships, carry obturators following maxillary resection, maintain facial form, and restore facial features *(Converse and Valauri, 1966)*. Guide plane appliances can be used effectively when teeth are present *(Adisman, 1962; Ackerman, 1955)*.

Exotic appliances have been suggested for edentulous resected mandibles. They usually result in soreness and frequent adjustment and repair. Complicated mechancial devices are difficult to accommodate and keep clean and require careful maintenance *(Emory, 1947)*. Mechanical guide planes cannot be used in edentulous situations. The use of a second row of teeth in the maxillary denture has been suggested *(Rosenthal, 1964)*. The teeth are arranged in a Monson curve with desirable inclines. This helps orient the residual mandibular segment to correct the sagittal relationship and provide a good occlusal table. A similar result can be achieved through the use of a wax ramp palatal to the maxillary molars *(Swoope, 1969)*. These appliances serve as training devices and provide acceptable occlusal function.

**RESILIENT MATERIALS.** In the presence of defects, unusual occlusal configurations are sometimes required. Another approach is the use of resilient materials on the tissue surface of appliances where the tissues respond poorly to loading. The use of silicone materials has been shown to have some benefit. They tend to partially absorb forces and result in a more advantageous distribution to the basal seat *(Laney, 1970).* There are, however, a number of problems with adjustment, processing, and home care *(Gonzalez and Laney, 1966).* Long-term maintenance is a problem because of staining, deterioration *(Bell, 1970),* and growth of organisms *(Gibbons, 1965).* The acceptance of the materials by the patient is not always favorable *(Woelfel and Paffenbarger, 1968).* In certain instances they have been found to be very helpful to aid in overcoming specific mechanical problems *(Laney, 1970).*

## EXPERIMENTAL DESIGN

There is a paucity of information on human factors in dentistry. This is particularly true in the area of denture acceptance. Since determination of human factors or emotional status is crucial to the success of treatment, better prognostic aids must be developed. There needs to be controlled investigations into patient attitudes and feelings toward dentists, dental care, and dentures. Information from these studies would be helpful to provide better sensitivity and insight for the dentist. It would help him become more perceptive of patient needs.

Some questionnaire studies have been performed to help evaluate patient attitudes toward dental care *(A.D.A. Bureau of Econ. Res. and Stat., 1958).* The basic steps in the scientific method should be followed in research and in clinical practice, such as; **a.** asking questions, **b.** making relevant observations, and **c.** interpreting observations in such a way as to answer the original questions. It has been said that the most creative part of science is asking questions. It is difficult to know which questions are relevant and how to pose them clearly. Base line studies on attitudes toward treatment will help identify fruitful areas for further and more specific investigation.

The relationship of emotional factors and facial pain or temporomandibular joint dysfunction has been documented by many authors. Testing with psychiatric interviews *(Brody and Nesbitt, 1967; Moulton, 1966)* and Minnesota Multiphasic Personality Inventory *(McCall, et al., 1960)* have shown positive correlation of emotional factors and joint dysfunction. Anxiety levels can be shown to increase prior to dental treatment using physiologic parameters of measurement, such as galvanic skin response *(Corah and Pantera, 1948).*

The relationship of periodontal problems and emotional factors has been studied. Use of the Minnesota Multiphasic Personality Inventory has shown a significant relationship *(Manhold, 1962).* Gingival disturbances are so common with emotional problems that acute necrotizing ulcerative gingivitis has been suggested as a model *(Giddon, 1966).* The mouth would serve as a prototype for study of psychophysiologic reactions.



There are some exploratory studies to test the relationship of human factors and denture acceptance. The Minnesota Multiphasic Personality Inventory has been used and certain questions modified to yield a "Denture Adjustment Inventory" *(Sobolik and Larson, 1968).* Success was increased when patient participation in determination of esthetics was encouraged *(Rosenthal, Pleasure and Lefer, 1964).* There was a positive relationship between patient ability to adjust to health problems and denture satisfaction. This was tested by a questionnaire developed primarily from the Bell Adjustment Inventory *(Emerson and Giddon, 1955).* The use of the Cornell Medical Index has been investigated as a prognostic device *(Bolender, Swoope and Smith, 1969).* There was a significant relationship between emotional factors, general health, and denture satisfaction.

The information available is primarily from exploratory preliminary studies. There is a need for controlled investigation using multiple methods of evaluation. Better prognostic aids are needed for the practitioner. There is a need for the study of human factors in the dental curriculum. It is hoped that ideas for design of investigations will result from this Workshop and that those attending will be stimulated to use their talents in this important area.

## SUMMARY AND CONCLUSIONS

The literature contains many references to the role of human factors and denture success. There are endless discussions about the need for consideration of the total patient. There is little information on specific techniques and procedures to help the dentist achieve these objectives.

The need for better training of the dentist is obvious. He should study psychology in his undergraduate predental curriculum. The dental school curriculum should include specific courses in human factors. Most dentists and dental schools pay lip service to the concept that human factors are important, but few are willing to make a commitment of time and resources.

The dental student should have an understanding of the basic psychological mechanisms. Motivation and anxiety are important for the success of the treatment he will render. He should be trained to be more perceptive of patient wishes and feelings. Efficient and effective interview techniques should be learned. Tape recordings and videotapes can be used to critique and evaluate dentist-patient relationships.

The need for further research is evident. The clinician needs better clinical prognostic tools to identify potential problems early. He also needs training, by continuing education, to improve interpersonal relations with patients. The need for evaluation and perception of human factors has been emphasized throughout this review. An excellent technical treatment can fail if these factors are ignored.

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# SECTION REPORT

## INTRODUCTION

Human factors as related to complete dentures is one of the most important areas of consideration in evaluating and treating the edentulous patient. The inclusion of human factors in this Workshop recognizes its importance.

Early in the sessions, the Section members learned that their direction of discussion was uncharted, that is, no rules or guides had previously been established. There was an awareness that sensitive and conscientious practitioners and teachers have long recognized the need to alleviate patient's fears and anxieties.

*The Section identified the following subjects for discussion:*

1. The human factors involved in the treatment of the complete denture patient
2. Factors which produce an adaptive response to complete dentures
3. Factors which produce a maladaptive response to complete dentures
4. The teaching of human behavior in dentistry
5. Methods of modifying the maladaptive behavior
6. The dynamics of the dentist-patient relationship
7. Techniques to identify adaptive and maladaptive responses to complete dentures
8. Suggestions for future research in human behavior in dentistry

## HUMAN FACTORS INVOLVED IN THE TREATMENT OF THE COMPLETE DENTURE PATIENT

Our objective is the successful treatment of complete denture patients. We identified a number of human factors and decided to categorize them into: **a.** intrapersonal, **b.** interpersonal, **c.** cultural, and **d.** physical factors.

The intrapersonal factors were identified as body image, fear of pain, fear of change, fear of impairment of function, fear of loss, and patient preconception and expectations. These factors needed to be evaluated to see if they were realistic.

Some of the physical factors were identified as endocrine, nutritional, factors of tissue tolerance, the effect of drugs, and anatomic abberations and general health index.

## FACTORS WHICH PRODUCE AN ADAPTIVE RESPONSE TO COMPLETE DENTURES

1. The acceptance of the dentist and confidence in the dentist, which could also be described as trust
2. Previous favorable experience with authority figures
3. The capacity to cope favorably with change. A positive attitude increases this capacity
4. Favorable physical conditions: youth and good general health were factors which produce an adaptive response to complete dentures
5. Realistic expectations of the patient
6. Good learning capacity
7. The desire of the patient to please the doctor. Recognition by both the doctor and the patient that there are varying degrees of success and acceptance of a less than ideal result by the patient and the doctor
8. Recognition by the patient of the limitations he brings to complete success with complete dentures and acceptance of this fact.
9. Good physical coordination on the part of the patient
10. The therapeutic alliance of the patient with the doctor is a very important factor in achieving a favorable adaptive response. The patient should be aware of the active role he must play in the cooperative treatment effort.

## FACTORS WHICH PRODUCE A MALADAPTIVE RESPONSE TO COMPLETE DENTURES

1. Lack of trust in the dentist
2. Poor communication between the dentist and his patient
3. Negative previous experience, such as unfavorable experiences with other dentists, or authority figures, or ones own parents that had been transferred to the dentist
4. Unrealistic expectations of the denture patient
5. Resistance to change arising from severe anxiety or depression or hopelessness
6. Low tolerance for anxiety or pain
7. A high level of anxiety on the part of the patient
8. Inadequate tissue tolerance



9. Muscle incoordination
10. Chronic dissatisfaction
11. The wish to fail. The patient wants attention and needs a continuing relationship with the doctor. The denture failure is used to accomplish this because the patient cannot achieve it in any other way.
12. Disapproval of the dentures or of the individual with dentures by people important to him

## THE TEACHING OF HUMAN BEHAVIOR IN DENTISTRY

The dentist is knowledgeable in the technical skills he uses in dental practice. From his patient contact experiences he learns that human behavior plays an important role in the success or failure of his treatment program. Human behavior has been learned at the apprenticeship level. The Section on human factors recommends the inclusion of human behavior studies into the dental curriculum. It is also important that we do not seek to change the orientation of the curriculum completely, but suggest a program which is people-oriented, in addition to the traditional technical procedures.

Teaching of human behavior includes two broad categories. One involves teaching of human behavior in schools of dentistry to predoctoral and postdoctoral students. The second category concerns itself with teaching human behavior to dentists in practice.

In teaching human behavior in schools, it is necessary to obtain a commitment regarding the importance it will give this discipline. For example, would a school commit funds for research and faculty salaries of personnel employed specifically to work on problems of human behavior in dentistry? Would a school of dentistry consider the human factors curriculum in the same category as other learning disciplines? If necessary, would it retard a student's graduation, if he did not demonstrate proficiency in this area? Human factors must be made a part of the every day dental school learning experience. For example, if a student is taught the technique of the initial interview with a complete denture patient, and is not required to use this when he interviews his patient in the clinic, he will not benefit from this knowledge. Teachers should not only be familiar with dentistry but have special interests in human behavior. In planning the curriculum, it is necessary to adopt a team approach involving dentists and mental health specialists. The dental school has two major responsibilities to this program and its students: to create a favorable climate for the teaching and practice of human behavior, and to encourage an approach emphasizing the total patient. This approach must be integrated with the traditional regard for technical excellence.

In order to encourage receptivity to teaching human behavior, faculties should be exposed to the fundamentals. Their example will reinforce a philosophy of dental teaching which incorporates technical excellence with the understanding of the patient as a human being.

Courses in psychology should be a predental requirement. In selecting dental students, a portion of the aptitude testing should include measurement of the applicants' concern for and interest in people.

Development and integration of human behavior into the dental curriculum must occur at every level of student training. We must weld the disciplines of psychology and dentistry so that the contributions in both fields can be brought together. Two examples of such curriculums are outlined. In one, team teaching by dentists and mental health personnel is used. It is a four-year program which includes seminars with special techniques such as role playing and video tape. Subject matter includes psychophysiologic disorders, patient interview techniques, psychology of pain, dentist-patient relationships, and anxiety reduction. In the other example, the course consists of eight lectures to the sophomore class and eight lectures to the senior class. For the sophomores in their preclinical years, course content deals with basic psychology relevant to dentistry. It is approached by using the feelings of the students to learn of patient feelings. In the senior year, the lectures deal with the practical application of psychological principles to dental practice.

Suggested guidelines for a typical curriculum course content includes reactions to authority figures, patient expectations, and the influence of past experiences. It also includes exaggerated unrealistic expectations that patients may have toward authority figures, nonverbal communication, history taking, and attention to consideration of subjects to which the patient must make an adjustment similar to the adjustment to dentures; for example, adjustment to bifocals. Psychology of loss and psychology of convalescence are two other topics which could be taught. Strong emphasis on the importance of the doctor-patient relationship is the key to effective dental therapy. Postdoctoral student curricula would be structured similarly but with special modifications as indicated for each specialty. Graduate students would be exposed to more difficult problems and need a more thorough education in human behavior.

Teaching human behavior in dentistry includes dentists in practice. With the heightened emphasis on continuing education today, there should be many opportunities for dentists to receive additional knowledge of human behavior. Dental schools should institute continuing education courses on an individual course basis and they should be encouraged to institute participating courses as ongoing study clubs. This kind of teaching is the most productive device for teaching human behavior because it relates to the practical problems of the practitioner's daily practice. Nothing improves an individual's skill faster than learning by doing.



## METHODS OF MODIFYING MALADAPTIVE BEHAVIOR

When maladaptive behavior is recognized, it is possible to effect a change. Changing a maladaptive patient to one who can adjust to wearing complete dentures involves many factors, including trust, time, and tenderness. This Section identified three areas from which maladaptive behavior originates: psychologic origins, physical deficiencies, and technological deficiencies or treatment inadequacies. The clinician recognizes maladaptive behavior manifested by gagging, repeated previous failures with dentures, anxieties, phobias, and fears.

Refusal to take care of himself physically may result in needless chronic illnesses such as malnutrition and hormonal deficiencies.

Three categories of treatment are available. One is dynamic treatment, utilizing respect, support, concern, understanding, and demonstrating the competence of the dentist. The relationship which emerges from these expressions of concern is a most profound influence on changing a maladaptive response to one which is successful for the patient. The second treatment method is a behavioristic one and involves dynamic concerns such as support and understanding and are applied via conditioning procedures. The treatment of physical deficiencies often aids in overcoming psychological and other maladaptive responses. For example, when systemic illnesses or nutritional problems exist, successful treatment may change the patient to an individual who can wear dentures.

The third type of treatment is the correction of technological inadequacies in dentures. An example of a common and dramatic maladaptive behavior is gagging. As dentists, we are concerned with pathological gaggers. These are individuals whose natural gag reflex is greatly augmented by psychogenic factors. Underlying these manifestations are root causes which may be an expression of rejection of the denture or an expression of fear of respiratory obstruction. Treatment of the gagging patient may be dynamic or behavioristic. For the patient who fears windpipe obstruction, behavioristic treatment would include such techniques as desensitization, suggestions, distraction, the use of topical anesthetics, medications, and training devices. Where gagging is an expression of the fear surrounding loss, a dynamic approach is the treatment of choice. The dentist needs to offer support, understanding, and sensitive appreciation for the patient's feelings and problems.

The dentist must be aware that his therapy has limitations and should be prepared to refer the patient for more specialized care if necessary.

## THE DYNAMICS OF THE DENTIST-PATIENT RELATIONSHIP

There are factors which both facilitate and disrupt this most important relationship. An awareness of facilitating factors aids the dentist in building a positive and influential relationship with his patient. These factors include open communication, awareness and control of one's own feelings, respect for the patient, praise of the patient, sensitivity to the patient's feelings, and a strong desire to work together. The dentist's ability to reassure the patient, inspire confidence in his patient, be empathetic, and recognize the patient's concerns and needs, contributes to this relationship.

Disruptive factors cause serious damage to the final therapeutic result and can precipitate maladaptive responses. They may be manifested verbally, nonverbally, or in the form of innuendos. The disruptive influences evoke hostility in either the dentist or the patient. This feeling is an emotional response to frustration. It may be evoked by status differences between the patient and the dentist, by fatigue in either the dentist or patient, or by preoccupation with one's own goal without consideration of the other's needs.

The patient may imbue the dentist with characteristics of authority figures that were present in his life in the past. A patient often carries over attitudes that he felt toward his parents, and transfers them to the dentist. Sometimes these transferred feelings are of a hostile nature and can be very disruptive in the dentist-patient relationship.

## TECHNIQUES TO IDENTIFY ADAPTIVE AND MALADAPTIVE RESPONSES TO COMPLETE DENTURES

1. Interpretation of the initial contact with a patient by observation of the patient's manner
2. Questionnaires. What the section members wanted to emphasize was that the content and manner of response to these questions provided important identifying data
   (a) Patient information questionnaires
   (b) Health questionnaires
   (c) Cornell Medical Index
3. Interviewing techniques
   (a) The patient and dentist evaluate each other
   (b) History taking
      (1) Dental history taking
      (2) Health history taking



4. Observation of appearance and behavior of the patient
5. The preliminary treatment which may be diagnostic in nature, such as proper extension, correction of vertical dimension, tissue treatment techniques, etc.
6. The clinical examination. What it means to the patient, the dentist's demeanor and his expression of confidence. The clinical examination may mean a great deal to the dentist. The physical findings are only part of it
7. The use of consultants
   (a) Other dentists
   (b) Mental health specialists
   (c) Medical consultants
   (d) Office personnel are good consultants

## SUGGESTIONS FOR FUTURE RESEARCH IN HUMAN BEHAVIOR IN DENTISTRY

The following recommendations were made:

1. Commitment by dental schools of: funds, personnel, curriculum time, and research
2. Commitment by individuals to study and research problems in human behavior
3. A development of cooperative studies with mental health personnel—a team approach between dentists and mental health personnel
4. Verification of commonly held beliefs about human behavior in dentistry are very important areas of research
5. Research into what is successful treatment
6. Research into adaptation of appliances
7. The use of mental health personnel together with the dentists to study problem denture patients
8. Research into the incidence of gagging and the nature of gagging
9. To study the relation of dentist characteristics and denture success
10. To study the adaptive capacity of individuals
11. To study the relationship of emotional factors to all aspects of dentistry, not just complete dentures—rather problems of the temporomandibular joint, periodontal problems, caries, bruxism, and preventive dentistry
12. To study the nature of anxiety and pains
13. To study the change in body image and interpersonal perception

## SUMMARY

There is a preponderance of evidence which shows that human factors constitute one of the least understood and most meaningful areas in the practice of dentistry, particularly in the field of complete dentures. The dental school curriculum is almost devoid of formal recognition of this problem. It was evident that the field of human factors was so vast, that the Workshop barely scratched the surface in its attempt to cover it. There was an obvious lack of research-verified information. The future status of prosthodontic treatment will depend upon a favorable and dynamic dentist-patient interaction rather than mechanical or technical skills.

## CONCLUSIONS

1. Human factors is one of the most important considerations in successful denture construction.
2. Human factors are very complex.
3. Many theories and few facts exist concerning the role of human factors.
4. The dentist-patient relationship is of great importance and is often critical to successful treatment.
5. There is little available information on the role of human factors.
6. The role of human factors is unfortunately neglected by many dental schools and practitioners.
7. Dentists need to treat the "individual person," showing concern and empathy.
8. The recognition of human factors as a Section in this important Workshop is appreciated.
9. Future workshops in human factors would be extremely meaningful.
10. Dental faculties designated to teach human factors should be so trained.

This report represents the unanimous opinion of this Section.

Respectfully submitted,

Alex Koper, *Chairman*
Marvin S. Weckstein, *Secretary*
Charles C. Swoope, *Reviewer*
Marvin O. Barnett
Dewey H. Bell, Jr.
Nathan Friedman
Warren W. Goodwin
Barry Hirsch
Richard H. Kingery
Chester K. Perry
Thomas H. Shipmon
Richard A. Smith
Walter H. Swartz
Frederick S. Muenchinger, *Section Assistant*

# DISCUSSION OF REPORT

Following the reading of the Section report by Koper, Swartz moved for its acceptance. The motion was seconded by Shipmon and approved by the voting members of the General Assembly.

## RE: THE TREATMENT OF THE COMPLETE DENTURE PATIENT

Ramfjord requested a reference stating that nutritional factors affect human behavior in the acceptance of dentures. Koper replied that the Section members recognized the fact that individuals who suffer from physical problems such as malnutrition often become depressed, hopeless individuals, and by correcting the deficiencies, the patient's attitude often changes favorably.

## RE: FACTORS WHICH PRODUCE AN ADAPTIVE RESPONSE TO COMPLETE DENTURES

Weinberg referred to an unpublished study of patient attitudes concerning new dentures and pointed out that the two most important factors regarding patient acceptance were: (1) if the patient liked the dentist as a human being, and (2) the patient's attitude toward wearing dentures. How well the dentures were constructed was apparently not an influencing factor.

Hickey questioned the scientific methodology used in the study cited by Weinberg and expressed his feelings that too often, little scientific effort is used to evaluate how well the dentures have been constructed when determining how well the patient adapted to them. Weinberg conceded that the study was a clinical evaluation and scientific methodology was not applied—just a clinical appraisal by each member of the study group.

## RE: TEACHING HUMAN BEHAVIOR IN DENTISTRY

Hickey commented that there are dental schools that devote salary money, research money, and time for faculty members to study these aspects of human behavior.

## RE: METHODS OF MODIFYING MALADAPTIVE BEHAVIOR

Mahan requested a definition for the term, "pathological gagger." Hirsch responded by stating that "from a behavioral viewpoint, a pathological gagger would be someone who begins gagging at the mere sight of the appliance, perhaps even an impression tray, with no physical contact." Koper added that the Section members wanted to differentiate gagging, which is a normal physical reflex, that is, a normal subconscious reflex to invasion, from gagging that is used to get rid of an unwanted or imagined unwanted object, which has psychological implications.

Zander requested a reference for the statement, "successful treatment of systemic illnesses or nutritional problems can change the patient to an individual who can wear dentures." Perry replied that this is an area where there is a lack of documentation. He said that ". . . when a patient is ill they may reject dentures because of the illness. If they have a circulatory or cardiovascular problem, the fragility of the capillaries underlying that denture make it very painful to wear. If they have a faulty calcium transport mechanism, the dentures are not so easy to wear, and if these can be corrected through nutrition and through health measures, their acceptance of the dentures may be better."

## RE: DENTIST-PATIENT RELATIONSHIP

Woelfel commented that more time should be devoted to dentist-patient communication with less responsibility given the assistants to explain complete denture service. Koper responded, "time and tenderness are tools for changing a maladaptive response to an adaptive one." Woelfel continued, stating that "the dentist should be the one to spend more time before, during, and following the construction of dentures; talking to the patient to avoid misunderstandings."

Taylor indicated that it would be appropriate to recognize that the dentist might also be transferring identification in a maladaptive sense to his patient, and that it is a two-way response between the dentist and his patient . . . that perhaps the dentist needs to learn to evaluate his own responses as well as learning to recognize and evaluate the types of patient responses.



## RE: SUGGESTIONS FOR FUTURE RESEARCH

Henderson requested further explanation regarding the expression, "adaptation to appliances." Koper explained that the Section members meant research into the nature of an individual's adjustment to a foreign body in his mouth, including complete dentures. Henderson replied, "I respectively submit, in deference to the dignity of prosthodontics, we are talking about restorations and not necessarily appliances." Koper commented that Henderson's objection was well taken.

## RE: SUMMARY

Henderson objected to the sentence, "the future status of prosthodontic treatment will depend on a favorable and dynamic dentist-patient interaction rather than mechanical or technical skills," and indicated that such a statement inferred that technical excellence is not important. Henderson felt that it *is* important. Koper accepted this correction.

# Index

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