ABSTRACT

Title of Thesis: The effect of number and distribution of maxillary implants on the load under implant-retained overdentures

Thesis Directed by: Dr. Radi Masri

Assistant Professor

Department of Endodontics, Prosthodontics and Restorative Dentistry

Baltimore College of Dental Surgery

University of Maryland

Purpose: to evaluate the effect of the number and distribution of dental implants on the occlusal pressure transmitted to the palate.

Material and Methods: eight implant analogs were placed in a replica of maxilla in the areas of teeth number 3, 4, 5, 6, 11, 12, 13 and 14. Locator attachments were attached to the implant analogs. The distances between the centers of implant analogs on each side were 8 mm. Fifteen denture bases with occlusal rims were fabricated to fit on the maxillary replica. Under a load of 245 N, pressure on the palate was measured under each denture base in six different designs of Locator insertions: No Locators, 2 Locators, 4 Locators with distances of 8, 16, and 24 mm and 8 Locators. Data was analyzed using One-Way ANOVA and Tukey's HSD test. A p value of ≤ 0.05 was considered significant.

Results: Pressure transmitted to the palate ranged from 20.67 +/- 16.06 N (mean +/- SD) for overdentures supported by 8 Locators to 85.61 +/- 27.94 N for a conventional denture (control). The amount of pressure transmitted to the palate when the overdentures were supported by 4 Locator attachments, was significantly lower than when no, or when two Locator attachments were used. However, they were not significantly different from each other. When the overdentures were supported by 8 locator attachments, the pressure transmitted to the palate was significantly lower than that of conventional dentures, overdentures supported by 2 Locator attachments and overdentures supported by 4 Locator attachments when the distance between the anterior and posterior implants was 8 mm.

Conclusion: Using 4 Locator attachments produced significantly less pressure on the palate, compared to when zero or two Locators were used. When the distance between the 4 Locators was 16 or more mm, the pressure was not significantly lower than 8 Locator design, suggesting that the palate of a 4 implant-retained overdenture with a distance of 16 mm or more, does not contribute significantly to the pressure distribution under the overdenture. Considering the static nature of the load, the results of this study should be interpreted clinically with caution.

THE EFFECT OF NUMBER AND DISTRIBUTION OF MAXILLARY IMPLANTS ON THE LOAD ON THE PALATE UNDER IMPLANT-RETAINED OVERDENTURES

By
Sahar Damghani

Thesis submitted to the faculty of the Graduate School
of the University of Maryland Baltimore in partial fulfillment
of the requirements for the degree of Master of Science
2011

DEDICATION

I have tried not to cease to learn from my father to be brave and inquisitive, and from my mother, to be resilient and not to give up. I am hoping to learn from my sister, to love unconditionally. This thesis is dedicated to them.

ACKNOWLEDGEMENTS

I would like to express my deepest gratitude to the following people without whom the accomplishment of this research would not have been possible;

I am indebted to Dr. Carl Driscoll, my program director, a great teacher who has taught me discipline and the wisdom of working backward. I am grateful to my teacher, Dr. Elaine Romberg, for her immense help and insight with statistics and for being patient with me. Also I am thankful to Dr Glen Minah for his support and insight on the project.

I appreciate the help and support of Dr. Elizabeta Evtimovska, Dr. Kian Ming Tan, and Ms Rose Morgan, during my residency and through the research project.

Many thanks to all my co-residents, especially Dr. Kaye You, Dr. Caroline Nguyen and Dr. Farha Maidi, for supporting me during difficult times.

My special thanks to Mr. Paul Zuest from Zest Anchors for contributing to the research.

Above all, I would like to acknowledge and humbly thank my advisor, Dr. Radi Masri. Dr. Masri has been the greatest mentor and an honest and thorough human being who has guided me patiently and given me his insight in conducting and writing this thesis.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Complete dentures

Edentulism is decreasing, but still exists to a significant degree. In 1958, seventy five percent of Americans were edentulous by the age of 70 (Miller 1958), yet a report from the Surgeon General in the year 2000 mentions that 33 % of Americans over the age of 65 are completely edentulous. A complete denture, according to the Glossary of Prosthodontic Terms (GPT-8), is a removable dental prosthesis that replaces the entire dentition and associated structures of the maxilla or mandible. (GPT-8 2005) The purpose of fabrication of complete dentures is to (GPT-8 2005) replace the lost natural dentition and associated structures of the maxilla and mandible in patients who have lost all their remaining natural teeth or are soon to lose them. The decision of providing complete dentures is made only as a last resort, when all other means of treatment are exhausted. In this case, the dentures must be designed and constructed with an emphasis on the preservation of the remaining oral structures. (Winkler 1994) The loss of teeth affects different people in a variety of ways. While the majority of edentulous patients adapt readily, there are those who continually regret the edentulous state and who cannot accept or adjust to the limitations of complete dentures and will never master the use of complete dentures.

There are a few basic objectives of complete denture prosthodontics. The most important ones are restoration of masticatory function, facial appearance, speech, and the maintenance of the patient's health. The mastication of food with complete dentures should assist the patient in obtaining adequate nutrition. Complete dentures must restore the phonetic abilities of the patient and give patient comfort. Edentulous patients should be able to speak clearly and distinctly with complete dentures. Artificial teeth should duplicate the size and contour of the missing teeth and occupy as closely as possible the previous positions of their lost predecessors. Last, but not least, the emotional and psychological effects of improved appearance can create a new outlook on life for many patients. (Winkler 1994)

The base of a complete denture serves several very important objectives; it provides the patient primarily with support but contributes to retention and stability as well. Also, as importantly, it provides esthetics for the lips, and at the same time maintains the health of the oral tissues through alveolar ridge preservation (Boucher and Hickey 1975). Making an accurate impression is a crucial step to make sure these objectives are met.

Impressions and their significance in complete dentures

An impression is a negative copy of the surface of an object (GPT-8 2005), and a complete denture impression is a record of the negative form of the denture bearing tissues of the oral cavity and border areas of the edentulous mouth that make up the basal seat of the denture . (Boucher 1990)

Although many factors such as occlusion, interocclusal distance and the coincidence of centric occlusion with maximum intercuspation have influence on the final result of fabricating complete dentures, the effect of impression technique and impression materials on developing denture base and hence the preservation of both soft and hard tissues of the jaws is of utmost importance. (Rahn and Heartwell 1992)

Despite innovations in impression techniques, methods and materials, underlying principles and fundamentals remain constant. The end result is especially enhanced by giving attention to the pressure produced during the final impression. (Boucher 1951)

Alveolar ridge preservation

In making impressions for complete dentures, one of the primary objectives that one must try to meet is preservation of the alveolar ridge. The alveolar ridge will atrophy as the patient loses his natural teeth. This is probably due to loss of stimulation that the ridge receives from natural teeth. The rate and pattern of resorption varies among different individuals and within the same individual at different times. Tallgren concluded that the resorption is particularly marked in the anterior mandibular ridge with the mean, being approximately four times as great as that of the maxillary ridge. (Tallgren 1972)

Several important factors play a major role in the rate and pattern of alveolar bone resorption. These factors are anatomic, metabolic, functional, and or prosthetic.

Prosthetic factors include the impression techniques, materials, concepts, principles, and practices that are incorporated into the prostheses. (Atwood 2001) Other important prosthetic factors include occlusion, interocclusal distance, and centric jaw occlusion in harmony with maximum intercuspation. (Atwood 1971; Tallgren 1972) The prosthodontist should constantly keep in mind the effect the impression technique and the impression material may have on the support, stability, and retention of the denture base and the effect the denture base may have on the continued health of both the soft and hard tissues of the jaws. Pressure generated during the impression technique is reflected as pressure in the denture base and may result in soft tissue damage and bone resorption. (Heartwell and Rahn 1974)

Stability of the denture base

Stability, by definition, is the quality of the prosthesis to be firm, steady, or constant, to resist displacement by functional horizontal or rotational stresses. (GPT-8 2005) It differs from retention, in that stability resists forces in the horizontal plane whereas retention is the resistance to vertical dislodging forces. Stability ensures the physiologic comfort of the patient while retention contributes to the patient's psychologic comfort. (Jacobson and Krol 1983)

Stability, in general, depends on the inclination of the flanges, the form, size, and arrangement of the posterior teeth, the position of the posterior teeth in relationship to the foundational center, and the form of the polished surface. (Devan 1952; Fanuscu and Caputo 2004) Thus, the factors that contribute to the stability of the denture include the relationship of the denture base to the underlying tissue, the relationship of the opposing occlusal surfaces, and the relationship of the external surface and border to the surrounding orofacial musculature. Care must be taken in the recording of all three of these surfaces to ensure optimal stability of the final prosthesis.

Optimal denture stability requires that the overlying soft tissues that provide resistance to horizontal forces be properly recorded and related to the denture base, which is dependent on the impression procedure. It requires maximum use of all bony foundations where the tissues are firmly and closely attached to bone. While the tissues of the maxillary palatal inclines are ideally designed to resist forces applied to the denture base, the maxillary facial and mandibular lingual inclines may be less effective due to the thin alveolar mucosal covering. Positive and intimate contact of the denture base with these inclines, as limited by the nature of the overlying soft tissues, determines the degree of stability attained. (Boucher 1944)

Harmony developed between the opposing occlusal surfaces also contributes to denture stability. Regardless of the type of posterior tooth form or occlusal scheme used, the denture must be free of interferences within the functional range of the movement of the patient. The functional range of movement refers to the positions through which the mandible moves horizontally during normal speech, swallowing, and mastication. During both functional and parafunctional movements, the occlusal surfaces should not contact prematurely in localized areas because such contacts cause uneven stress to be transmitted to the dentures during function resulting in lateral and torquing forces and ultimately adversely affecting stability. Bilateral, simultaneous, posterior tooth contact in centric occlusion is essential. (Jacobson and Krol 1983)

Denture stability and retention are also dependent on the correct positioning of the teeth and the contour of the external surface of the denture, especially in regions where excessive alveolar ridge has been lost. The forces exerted on the external surface of the teeth and the polished surfaces are essentially horizontal. When the occlusal surfaces of the teeth are not in contact, the stability of the denture is determined by the fit of the impression surface and the direction and magnitude of forces transmitted through the polished surfaces. If the teeth were in contact all the time, the polished surfaces would have relatively little effect on denture stability. Conversely, if the teeth were never brought into contact, the occlusal surfaces would be relatively unimportant. In order to construct dentures that function properly in chewing, swallowing, speaking, etc., not only proper tooth position but also the fit and contour of the polished surfaces should be developed just as accurately and meticulously as the fit and contour of impression and occlusal surfaces. (Beresin and Schiesser 1976)

Retention of the denture base

Retention is that quality inherent in the prosthesis that acts to resist the forces of dislodgement along the path of placement. (GPT-8 2005) Boucher describes retention as the most spectacular yet probably the least important of all complete denture objectives. (Boucher 1944) However, retention provides psychologic comfort to the patient. A retentive denture contributes dramatically to patient acceptance of the finished prosthesis. Fish probably was one of the first to discuss the determinants of retention and differentiate between the tissue surfaces, polished surfaces and occlusal surfaces of a complete denture. (Fish 1964) Among these determinants, the tissue surface of the denture is of special importance. This determinant of retention is affected by many factors which include but are not limited to adhesion, cohesion, atmospheric pressure (Wilson 1920; Boucher 1943; Boucher 1951), interfacial surface tension (Page 1949), capillary attraction (Stanitz 1948), van der Wall's forces, optimal contact and neuromuscular control. (Moses 1953)

Adhesion, the result of close proximity, is the force involved in attraction between unlike molecules. Cohesion is the force whereby molecules of a matter adhere to one another. (GPT-8 2005) Cohesion is the attraction of like atoms, which are brought into atomic relation to each other. (Wilson 1920) When the interatomic spacing is exceeded, the atoms are held together only by adhesion, either by mass attraction or by an intervening adhesive substance. The thinner the liquid film between the contacting surfaces, the greater will be the adhesion. Thus, the intimacy of contact between the denture base and the mucosa with a thin film of liquid interspersed is ideal for the retention of dentures, and this is called "adhesion by contact". (Wilson 1920)

Atmospheric pressure acts to resist dislodging forces applied to dentures. It has been called a "rescue force." At sea level, it amounts to 14.7 psi. It requires a perfect seal of the periphery of the denture to be effective. There must be no air leak around the border of a denture. In order for this condition to be attained, the periphery of the denture must have a definite relation to the structures that limit it. These structures must be known and recognized. (Boucher 1943)The Greene brothers introduced atmospheric pressure as a means of denture retention and recommended the use of functional denture borders as opposed to passive borders in the fabrication of complete dentures.

Page described interfacial surface tension as a phenomenon similar to Wilson's "adhesion by contact". (Page 1947; Page 1949) Interfacial surface tension is the resistance to separation possessed by the film of liquid between two well-adapted surfaces. To be most effective with a denture base, the final impression should cause only minimal distortion or displacement of the soft tissue. In function, atmospheric pressure is superior to interfacial surface tension as a retentive force when forces are horizontal as well as parallel to the mean mucosal plane whereas interfacial surface tension will only resist forces perpendicular to the axes of surface tension forces. (Devan 1952)

Skinner studied retention and found that the thinner the film of moisture between the mucosa and denture base the greater the retention will be, and this will increase the interfacial surface tension. Also, when he perforated the denture in the ridge area the interfacial surface tension was not significantly reduced. But, when the perforations were made in the palate area, surface tension and hence, retention was decidedly decreased. This indicates the importance of complete palatal coverage in complete dentures. (Skinner and Chung 1951)

Capillary attraction is that quality or state which, because of surface tension, causes elevation or depression of the surface of a liquid that is in contact with the solid walls of a vessel. (GPT-8 2005) It is what causes a liquid to rise in a capillary tube, since surface tension tends to form a round surface on the liquid. When the adaptation of the denture base to the mucosa on which it rests is sufficiently close, the space filled with a thin film of saliva acts like a capillary tube and helps in denture retention. Therefore, the tissue surfaces of the denture must conform perfectly to the mucous membrane in order to limit the amount of the saliva under the denture. Capillary attraction is directly proportional to the area covered and the larger the area covered by a denture, which is limited by the anatomic form of the mouth, the stronger the force required dislodging it. (Boucher 1943)

Optimal contact is a biological factor that refers to the close adaptation of the denture base to the underlying soft tissue. To be effective, air must be excluded from the intaglio, and the fluid film must be as thin as possible. Intimate tissue contact is the biologic factor that promotes these conditions by eliminating air entrapment. The border seal maintains this relationship by preventing the ingress of air once the denture is seated. Border seal also maintains the thin fluid film at the denture border, allowing a meniscus to develop in response to displacing forces. There is disagreement among authors, as of the relative importance of factors contributing to retention. Contrasting research reports have been written in support of many of these factors; As much as Wilson and other proponents of the mucostatic theory believed that adhesion is the primary factor in retention (Wilson 1920; Howland 1921; Fry 1923; Sussman 1960), there were others who believed that atmospheric pressure together with peripheral seal is the most critical factor. Regardless of the relative importance, the impression technique plays a crucial role in determining the degree of intimate tissue contact and contributes to retention. (Jacobson and Krol 1983)

Support of the denture base

Denture support is the resistance of the denture to forces that are applied on it towards the basal seat. These mainly include forces of mastication. Support is dependent on the relationship between the intaglio of the denture base and the underlying tissue surface during varying degrees and types of function. It is important to develop support in order to maintain established occlusal relations and to promote optimal function with a minimum of tissueward movement and base settling.

Support may be considered from two perspectives. First, the maxillary and mandibular denture bases should conform to the underlying tissues so that the occlusal surfaces can correctly oppose one another at the time of insertion. Bilateral simultaneous contact should exist both at initial closure and under functional loading. Second, the denture bases should maintain this relationship for a period of time. This property indicates the need for consideration of denture support in terms of longevity. Without long-term support complete denture retention and stability also become compromised.

Initial denture support is achieved by using impression procedures that provide optimal extension and functional loading of the supporting tissues, which vary in their resiliency. Long-term support is obtained by directing the forces of occlusal loading toward those tissues most resistant to remodeling and resorptive changes. (Jacobson and Krol 1983)

Ideally, the soft tissues should be firmly bound to underlying cortical bone, contain a resilient layer of submucosa, and be covered by keratinized mucosa. The underlying bone should be resistant to pressure-induced remodeling. These characteristics minimize base movement, decrease soft tissue trauma, and reduce long term resorptive changes.

Effective support is realized when the denture is extended to cover a maximal surface area without impinging on movable or friable tissues and only those tissues most capable of resisting resorption are selectively loaded during function. The denture base should be allowed to make firm contact with those tissues most capable of resisting vertical displacement during function, and compensation should be made for varying resiliency of the tissue in order to provide uniform denture base movement under function and maintain a harmonious occlusal relationship. (Jacobson and Krol 1983)

The areas of support are divided into primary and secondary regions. The primary supporting areas in the maxilla are the posterior ridges and flat areas of the hard palate. The midline suture area and the incisive papilla may need relief as they do not tolerate pressure very well. The buccal shelves, posterior ridges, and the retromolar pads are considered primary supporting areas in the mandible. In situations that the ridge is poor or highly resorbed, the buccal shelves are usually the only available area of support. The secondary supporting areas in both maxilla and mandible are the anterior ridges and all ridge slopes. (Boucher 1951) However, the total area of mandibular support is significantly less than that of the maxillary support. The average available denture-bearing area for an edentulous mandible is about 14 cm^2, whereas for an edentulous maxilla, it is 24 cm^2 on average. (Boucher 1990) This means that the mandible is less capable of resisting occlusal forces than the maxilla and that extra care must be taken if the available support is to be used to advantage.

Impression making

Various materials and techniques have been considered for making complete denture impressions. The technique used for each individual patient should be selected based on the diagnosis of the basal seat and border tissues. Impression techniques are classified as: the functional impression technique (Freeman 1969; Collett 1970), the mucostatic non-pressure impression technique (Page 1949), and the selective pressure technique. (Boucher 1943; Boucher 1951)

Functional impressions are those made with greater force than is used with other impressions. Under occlusal pressure, the denture base is supported by compaction of the mucosa and at rest; the base is in a static relationship to the ridge with no blanching of the tissues. The borders of the functional impression are determined by border molding and are associated with maximal coverage of the denture bearing mucosa. Very viscous or stiff materials such as soft wax, dental compound, or tissue conditioners are used to make functional impressions. (Koran 1980)

There are several problems associated with the functional impression technique. The cooperation of the patient plays an important role. Also normal movements of the denture base may result in unnecessary areas of relief. The impression material like soft acrylic resin is not satisfactory, if it is used as a wash, without undergoing function for a sufficient time to let it flow and give the tissues a chance to rebound. (Freeman 1969) Finally, alveolar atrophy may result from either a positive or negative force. (Roberts 1951)

Mucostatics as Page described was "a principle, not a technique" and it has evoked considerable controversy in dentistry since. (Page 1946) A mucostatic impression was defined as a denture base impression that is an accurate negative of the ridge tissue in its normal passive form. (Page 1947) Advocates of the mucostatic technique indicate that tissue cannot be compressed; it can only be distorted. According to Pascal's law, pressure exerted on a confined liquid will be distributed equally in all directions within the liquid. Since tissues have a high fluid content, an enormous amount of pressure is required to compress them. Furthermore, any pressure on the mucosa will be transmitted in all directions to the underlying structures. Therefore, if an impression is made that distorts the tissue, and the base is not in equal contact at all points, the tissue, in its attempt to return to its natural position, will either unseat the base by breaking the seal or else undergo a pathologic change. (Freeman 1969)

According to advocates of mucostatic principle, interfacial surface tension is the only significant means of retention for complete dentures. The impression is supposed to cover only that portion of the denture-bearing area where the mucosa is rigidly supported by bone. No flange or just enough flanges is used to resist lateral forces. In order to achieve a perfect contact between denture base and tissue, any tissue displacement must be avoided to produce an exact duplication of the mucosa. Consequently, in order to produce the smallest tissue details, the impression material must be softer than the softest tissue impressed. Instead of using acrylic resin bases, metal bases are used to minimize dimensional changes during denture processing. (Freeman 1969)

The selective pressure technique, as advocated by Boucher (Boucher 1943) combines the principles of both pressure and non-pressure procedures. (Boucher 1943) The nonstress-bearing areas are recorded with the least amount of pressure, and selective pressure is applied to those areas of the maxilla and mandible that are capable of withstanding the forces of occlusion. Studies have shown that it is difficult, if not impossible, to control the actual pressures developed underneath dentures during the making of the impression. (Bohanan 1954; Freeman 1969; Collett 1970; Frank 1970; Masri, Driscoll et al. 2002; Al-Ahmad, Masri et al. 2006)

The proponents of selective pressure techniques recommended that the tissues of certain areas be displaced to gain specific advantages for retention and stability. (Wilson 1920; Boucher 1943) Both the intensity of the pressure and the degree of control of the pressure to obtain the desired result, depend on the proper use of available materials.

Frank pointed out areas of the mouth requiring special attention regarding pressure control during impression making and illustrated practical methods of increasing or decreasing pressure as needed. Areas of the edentulous mouth requiring little pressure are the palate, residual ridges, and areas of easily displaced gingiva. More pressure is needed in the border seal, on the buccal shelves, and against the retromylohyoid fossa. (Frank 1970)

Although Frank did not perform statistical analysis of his data, he reported major differences in pressures produced during maxillary edentulous impression procedures, using various impression materials. Frank used a pressure gauge to test a regular mix of irreversible hydrocolloid, a thin mix of irreversible hydrocolloid, polysulfide impression material, and zinc oxide eugenol impression material. He also tested the effect of tray modification on the pressure produced. He noted that a tray with relief space, escape holes and border molded with modeling plastic met the requirements for selective pressure application. Zinc oxide paste was the impression material of choice in most instances. It was concluded from his investigation that impression pressures could be controlled by tray design and material selections.

Masri and Al-Ahmad, both analyzed the pressures produced during maxillary and mandibular edentulous impression making procedures, using modern impression materials and various tray designs. Both of these studies used an oral analog similar to that in Frank’s study. However, in both studies, a pressure gauge system was used to test irreversible hydrocolloid, light body vinyl polysiloxane, medium body vinyl polysiloxane, and polysulfide impression materials. The effect of the tray modification on the pressure produced during impression making was also tested (Masri, Driscoll et al. 2002; Al-Ahmad, Masri et al. 2006).

Masri and Al-Ahmad, both found that all the tested impression materials produced some pressure during impression making. Medium body vinyl polysiloxane and irreversible hydrocolloid produced significantly higher pressure than light body vinyl polysiloxane and polysulfide impression material. Masri’s study found that tray modification was not important in changing the amount of pressure produced during maxillary impression making with any of the used materials. The impression materials used had more effect on the pressure than did the tray design. Use of light body vinyl polysiloxane and polysulfide was recommended to make maxillary edentulous impressions. (Masri, Driscoll et al. 2002) Al-Ahmad found similar results in making mandibular edentulous impressions. However, this study found that the presence of holes and/or relief significantly altered the magnitude of pressure produced by irreversible hydrocolloid and medium body vinyl polysiloxane but not light body polysulfide and light body vinyl polysiloxane. (Al-Ahmad, Masri et al. 2006) Taken together, these studies suggested that it is important to control the pressure during impression making. The ideal impression is one embracing all the edentulous areas that are to be utilized by the dentures, embodying a composite of the tissues at rest without any overcompression or displacement. Such an impression made with less or no pressure will ensure a positive adaptation of a denture.

Overdenture

An overdenture is a removable dental prosthesis that covers and rests on one or more remaining natural teeth, the roots of natural teeth, and/or dental implants. (GPT-8 2005) This approach to address some of the problems associated with complete dentures is not new and dates back to over 100 years. Henking stated that Ledger and Atkinson advocated leaving 'Stumps' under artificial dentures for support. He also has referred to many other terms that have been used to describe the same treatment concept; such as overlay denture, telescoped dentures, tooth supported dentures, hybrid prosthesis, crown and sleeve prosthesis, and the superimposing dentures. (Henking 1982) Today, with the stress on preventive measures in prosthodontics, the use of overdentures has increased to the point where it is now a feasible alternative to other treatment plan outlines in the construction of prosthesis for patients that have retained some teeth. (Winkler 1994)

Fabrication of an overdenture enables a dentist to use teeth that are broken or have compromised crown to root ratios to attain some retention and support for the prosthesis. The teeth are either prepared for telescopic copings or to receive intra-coronal or extra-coronal attachments.

The overdenture accomplishes several important goals. First, the teeth are maintained as part of the residual ridge. The prosthesis sits on hard tooth structure, rather than only soft tissue, thus having more support than the conventional denture. If attachments or parallel walls of copings are used, in addition to support, the denture will have more retention. (Winkler 1994) The second goal of preserving teeth is to preserve the alveolar bone height. The alveolar bone loss occurring after extraction of teeth sums to a 4 mm vertical loss during the first year, and will continue progressively, at a slower rate. The loss in the mandible is four times greater than in the maxilla. (Tallgren 1966; Tallgren 1972) Research shows that retention of mandibular canines in fabrication of an overdenture results in 8 times less reduction in ridge height. (Crum and Rooney 1978) The third important goal in retaining teeth is preservation of sensory input associated with periodontal ligament. The proprioceptive sensory receptors enable patient to be aware of occlusal contacts. This awareness may enable the patient to control occlusal forces. (Winkler 1994)

Dentures and retention

Complete denture retention and stability can influence a patient's ability to function and are intimately and directly related to patient confidence and comfort. A logical consequence of adequate denture retention is less functional movement and better stability. It has been demonstrated that patients whose dentures lack stability, particularly with the mandibular prosthesis benefit significantly from even slight increase in denture retention. When conventional complete denture therapy and sound prosthodontic principles result in inadequate denture retention and stability, patient satisfaction, confidence and comfort commonly suffer. (Burns, Unger et al. 1995; Burns, Unger et al. 1995)

Dental implants

In an edentulous patient, when a conventional denture is inadequate as a treatment, there are alternatives that aid in increasing retention and stability. These include surgery to augment the alveolar ridge or increase vestibular depth or placement of dental implants to provide anchorage for an implant/mucosa supported prosthesis.

Implants were first introduced to dentistry by Branemark in 1969 and have been used since. The first North American comprehensive study conducted by Zarb in 1990 clearly showed high success rates and favorable outcomes of Branemark concepts. Another objective of that study was to introduce criteria for success of osseointegrated implants. In the study, 46 edentulous patients with prior unsuccessful conventional dentures were treated with osseointegrated implants and subsequent fixed or removable prostheses. The patients had been edentulous for 5 years or longer and reported chronic inability to wear dentures, usually the mandibular denture. Two hundred sixty-eight implants were placed in the 49 arches for an average of 5.47 implants in each dental arch. Success criteria for osseointegration was defined and was used to evaluate the placed implants at each annual recall appointment for data recording from 1979 up to summer of 1988. The criteria were: 1. Immobile individual implants after removal of prosthesis, 2. No radiographic evidence of peri-implant radiolucency, 3. Minimal radiographic vertical bone loss around implants, 4. Absence of persistent peri-implant soft tissue complications, 5. Surgical retrievability with minimal morbidity permitting easy resolution of prosthodontic problems. The result was an 89.05% rate of osseointegration for individual implants, which was a success. When less than 5 implants were available, implant supported overdenture was the treatment of choice. The conclusion of this study demonstrated that osseointegrated dental implants are a predictable alternative for supporting prostheses in edentulous jaws. (Zarb and Schmitt 1990; Zarb and Schmitt 1990; Zarb and Schmitt 1990)

Other studies have come to similar success results; Adell in 1981 reported a success rate of 91% mandibular and 81% in maxillary implants over a period of 5 to 9 years. (Adell, Lekholm et al. 1981) Van Steenberghe in 1989 reported the results of a multicenter study in which partially edentulous patients were treated with implant supported prostheses and followed them for 6 to 36 months after treatment. The results showed a survival rate of 87% in the maxilla and 92% for the mandible. (van Steenberghe 1989)

To summarize, as best described by Zitzmann, there are three concepts of implant assisted reconstructions in the edentulous jaw; 1. implant supported fixed prosthesis, 2. removable implant-supported overdenture, and 3. combined implant-retained/ soft tissue-supported overdenture prosthesis. (Zitzmann and Marinello 2001)

Implant retained overdentures

The implant overdenture is an especially attractive treatment because of its relative simplicity, minimal invasiveness, and economical feasibility. According to the McGill consensus statement on overdentures, a 2-implant overdenture should become the first choice for treatment of the edentulous mandible over the traditional complete denture. (Thomason 2002) Existing complete dentures can be converted for many patients and maintain facial support with the denture flange when moderate to extreme alveolar ridge resorption is present.

There are several advantages for implant retained/assisted overdenture over the conventional denture. The alveolar bone loss occurring after the extraction of teeth is measured as 4 mm vertical loss during the first year, and will continue progressively, at a slower rate. The loss in the mandible is four times greater than maxilla. (Tallgren 1966; Tallgren 1972) Studies on bone resorption under implant overdentures show rates of 0.6 mm vertical resorption over the first five year and 0.1 mm per year in long-term. (Adell, Lekholm et al. 1981; Jemt, Chai et al. 1996)

There is always some movement associated with even the most stable of mandibular dentures during function. This results in difficulty maintaining specific occlusal contacts and control of masticatory forces. Also, during different movements or speech, contraction of the mentalis, buccinator and/or mylohyoid muscles may dislodge the denture. One potential consequence is clicking noises due to contacts of teeth during speech.(Misch 2005) An implant overdenture provides stability of the prosthesis, hence enabling patients to reproduce centric occlusion. (Jemt and Stalblad 1986) Also, it is the retention provided by implants which keeps the denture in place. Thus, the tongue and peri-oral musculature, not having to limit the denture movements, will assume a more normal position. (Misch 2005)

A few studies have compared masticatory efficiency of implant-retained overdentures, root retained overdentures, and traditional complete dentures. Subjects with mandibular implant-supported overdentures need 1.5 to 3.6 times fewer chewing strokes than complete denture wearers to obtain an equivalent reduction in food particle size.

(Geertman, Slagter et al. 1994) The chewing efficiency with a traditional overdenture is improved by 20% compared with a traditional complete denture. (Rissin, House et al. 1978; Sposetti, Gibbs et al. 1986) Mericske-Stern compared mastication between root overdentures and implant overdentures. The former was more discriminative, whereas the latter developed slightly harder chewing strokes and tended to masticate more vertically. (Mericske-Stern 1993; Mericske-Stern, Hofmann et al. 1993)

There are also several advantages of an implant-retained overdenture over an implant fixed restoration. Davis mentions several situations where an overdenture should be considered as an option over a fixed restoration. Among these are 1. Patients with resorption of the residual ridge to an extent limiting the placement of the number of implants needed for fixed restoration, 2. Unfavorable arch relationships that makes positioning of the teeth in relation to implants difficult or impossible, 3. Patients with inadequate facial support, an overdenture will improve the appearance, 4. Implant overdenture is less expensive, hence financially more feasible for patients, 5. Situations where fixed restorations create phonetic problems, such as escape of air or saliva under the prosthesis, and 6. When a patient is well adapted and adjusted to use of complete dentures and is merely seeking some improvement in stability and support of the prosthesis. (Davis 1990)

As mentioned before, an implant overdenture prosthesis is supported by both implant and mucosa and generally requires fewer implants when compared with the fixed, completely implant supported prosthesis design. Two dental implants are usually considered the minimum number necessary for mandibular implant overdenture treatment. (Thomason 2002) In this type of prosthesis, the mucosa and implants together, will provide support, retention, and stability. As more implants are used, responsibility for these functions shifts from the mucosa to the implants. According to Misch, the implant overdenture may reduce the amount of soft tissue coverage and extension of the prosthesis. This is especially important for new denture wearers, patients with tori or exostoses or low gagging thresholds. Also, the existence of a labial flange in a conventional denture may result in exaggerated facial contours for the patient with recent extractions. (Misch 2005) Misch believes that implant supported prostheses do not require labial extensions or extended soft tissue coverage. If enough implant support is provided, the resulting prosthesis may be completely supported, retained, and stabilized by the implant. (Misch 2005) However, improvement to the overall performance of the prosthodontic treatment provided by using additional implants is not clearly understood.

Attachments

Root retained or implant-retained prosthesis are connected to the denture by means of attachments. An attachment is a connector that is composed of two or more parts. One part is attached to the implant, tooth or root and the other part is connected to the prosthesis.

Augsburger cited Hall, who mentioned that the concept of an attachment for a removable partial denture dates back to 1890's. In 1913, Gilmore presented his method permitting the use of isolated remaining root structures for retention and stabilization of removable prosthodontic appliances. (Augsburger 1966) The Gilmore bar attachment paved the way for attachment-supported overdentures. Mensor in 1973, described a classification system for selection of attachments. (Mensor 1973) Today, endosseous implants are being used in the same manner as were tooth roots more than 100 years ago and they have been shown to be reliable abutments for retention and support of overdentures. (Adell, Lekholm et al. 1981)

In summary, there are two general methods for using implants or natural teeth as the supporting or retentive part of an overdenture. The first method uses teeth or implants as independent units, connected individually to an overdenture. While the denture base properly contacts the mucosa, the simultaneous interlocking of attachment components provides the retentive quality for these systems. This type of attachment is called the stud-type and can be either intraradicular or radicular. They can also be either simple, nonresilient or have a spring-loaded component incorporated in them to render them resilient. (Mensor 1978) The pioneer examples of stud attachments are Gerber (Cenders and Metaux S.A, Biel, Switzerland), Introfix (Metaux Percieux S.A., Neuchatel, Switzerland). (Mensor 1978) The examples of some of today's available systems for usage with dental implants are ERA (Sterngold, Attelboro, Mass), O-ring System, Dalla Bona, or magnet attachments. This technique is more commonly selected when 2 implants are used. This may be because of the desire to simplify treatment. Additionally, abutment parallelism can be more critical with independent implant systems and this necessity can be increasingly more difficult to achieve as greater numbers of implants are involved. The evolution of some attachment systems such as the ERA or Locator has provided angled abutments, which allow additional latitude in this regard.

The ERA implant attachment consists of a nylon male that is housed in the overdenture and a titanium female part, which is inserted into the implant. The female parts are made to fit most common implant systems. The male attachment is designed to provide 0.4mm of resilience in the system. In the O-ring attachment system, the male is made of titanium and the female rubber O-ring is retained in a metal retainer ring.

The second method employs a rigid interconnection between implants using a cast metal bar. The overdenture is fabricated to passively fit adjacent mucosa for support. The abutment connection between the bar and denture base provides for the attachment's retentive quality. Hader, milled and Dolder bars are examples of such means of attachment. The Hader bar has a key-hole cross section. The plastic clip, which is located inside the prosthesis, is the means of attachment and provides some rotational resiliency of the prosthesis. In the case of milled bars, the bar is directly screwed onto the implants and a removable denture is fabricated to fit over the bar. This type of bar does not allow rotational resiliency and provides frictional retention.

Locator attachments

Locator attachments were introduced to the market in 2001 by Zest Anchors. (Schneider and Kurtzman 2001) The manufacturer claims that this type of attachment is "self-aligning" and patients can easily seat the prosthesis without the need for accurate alignment of the attachment components. The attachment is designed with a self-correcting, "Locating skirt" which allows the patients to seat the overdenture into the right position regardless of their dexterity abilities. According to Zest Anchors, patients can even "bite their prosthesis into place like they say they don't".

The retention of a Locator attachment is provided by both extra and intra-coronal parallel components and this property gives them a unique durability. A study conducted by Delsen Testing Laboratories (Independent laboratory contracted by the manufacturer) comparing various attachments found that the ERA attachment lasted 3,000 cycles (equivalent to 1-2 years of clinical use) and the Locator attachment lasted 60,000 cycles (20 times longer than ERA). (Schneider and Kurtzman 2001) There are however, no published studies to support this statement. The Locator attachment has the lowest height, 3.7 mm, as compared to the next available height of an attachment, 4.85 mm. (Menicucci, Lorenzetti et al.) Also, the nylon male pivots in its stainless steel cap, permitting 8-degrees of rotation without any resulting loss of retention and the retention is 4.0 - 5.0 lb as compared to 3.0 - 4.0 lb for ERA. (Schneider and Kurtzman 2001) This design features the benefits of the minimal height requirement and greater cross section for strength. (Schneider and Kurtzman 2001) The Locator attachment is available with three different retention males; 1. white – standard retention, 2. pink – light retention, and 3. blue – extra light retention

There is also the extended Range Locator attachment, which is used when implants are angulated is available with two different retention males: 1. green – standard retention; and 2. red – extra light retention. The research on this type of attachment is limited.

Choice of attachment

Questions regarding the most effective mode of attachment between the overdentures and supporting implants remain unanswered. In elderly patients, attachment systems that permit ease of prosthesis placement and removal, and those that are readily hygienic may be preferable. Other factors influencing the choice of attachments are the retention required, the amount of space available, and load distribution to the mucosa and to the implants. (Zitzmann and Marinello 2001) Patient compliance for recall and need for maintenance is another important parameter to consider. (Sadowsky and Caputo 2000)

According to Shafie, patients with advanced resorption of the alveolar ridge are good candidates for bar telescopic attachment assemblies, which have great horizontal stability. When available space is limited due to minimum alveolar ridge resorption, studs or magnets are better choices. Also, in cases of narrow ridges, a bar would interfere with the tongue space, hence making the studs a better choice of attachment. (Shafie 2006)

Retention of the attachment has always been a concern in terms of selection of a system. Investigators have studied the retention values of attachments. A few of those studies measured the absolute retention values of different attachment systems. Others measured those values at different pull cycle numbers to simulate and compare the retention after certain amount of usage. These studies suggest that the retention decreases over a period of time until it reaches a stable amount, but overall, they prove the clinical efficacy of all attachment systems.

One study by Chung et al. compared the retention characteristics of nine overdenture attachment systems. This study measured peak load to dislodgement and also the amount of strain at dislodgement. The authors grouped attachment systems into high (ERA gray), medium (Locator LR white, Spheroflex ball, Hader bar and metal clip, ERA white), low (Locator LR pink) and very low (magnet groups). (Chung, Chung et al. 2004)

Rutkunas et al. proposed that the retention of attachments will diminish quickly over a period of time, until it reaches a stable retention. They studied the minimum number of cycles required to reach stable retention. They also compared retentive force of overdenture attachments after they reach stable retention. (Rutkunas, Mizutani et al. 2005) This study evaluated ERA (orange and white), Locator Root attachment (pink) and OP anchor # 4 (Inoue attachment Co., Ltd, Tokyo, Japan) and magnetic (Magfit EX600W) (Aichi Steel Corp., Aichi, Japan) Maximum retentive force was measured initially and after each 40 cycles. Decrease of retention was characteristic for all attachments except OP. After fatigue Locator Root (pink) was most retentive. Magnetic attachments preserved maximum amount of retention measured at the baseline (98%). ERA Orange and ERA White attachments have preserved only 25% and 37% of initial retention respectively. This study concluded that due to fatigue overdenture attachments gradually lose their retention. Stud attachments are more susceptible to fatigue than magnets. They concluded that eight hundred cycles are required to achieve relatively stable retention of overdenture attachments.

Gamborena et al investigated the retention of the four different color-coded ERA attachments prior to and after various levels of fatigue loading (at baseline, at 500 cycles, and after every 500 cycles up to 5,500 cycles). The results of this study demonstrated that although there are four different retentive elements supplied by the manufacturer of the ERA system, there were only two significantly different groups; 1. the white attachments and 2. the orange, blue, and gray attachments ($P < .05$). After 500 cycles, there was a loss in retention of 60% for the white, 60% for the orange, 56% for the blue, and 54% for the gray. After 1,500 cycles there was no difference in retentive values for any of the four colored attachments. This number is close to the result of Epstein et al., who found that there is no difference in retention between the six types of attachments tested, after 2000 pull cycles. (Gamborena, Hazelton et al. 1997; Epstein, Epstein et al. 1999)

There are studies concluding that a much lower number of pulls and insertions are needed to reach the stable value. Breeding et al. studied the effect of simulated function on two designs of bar- clip (one clip and two clips). They concluded that use of two clips increased retention of the simulated prosthesis. They found dramatic loss of retention after the first removal of bars from clips. According to Breeding, simulated function did not cause a significant change in retention for either group after the twelfth pull. (Breeding, Dixon et al. 1996)

Epstein et al. compared the retentive properties of six prefabricated overdenture attachment systems. They concluded that the attachment systems with the highest initial retention, had the most rapid changes or greatest reduction with pull cycles than those with lower initial retention. (Epstein, Epstein et al. 1999)

Recently, researchers have tried to determine the same aspects of retention of attachments with angulated implants. One of these studies, Gulizio et al., investigated the effect of implant angulations upon retention of overdenture attachments. This study investigated the retention of gold and titanium overdenture attachments when placed on ball abutments positioned off-axis. They found that the angle had an effect upon the retention of gold matrices, but not for titanium matrices. (Gulizio, Agar et al. 2005)

A study by Evtimovska et al. measured retentive values of Locator attachments. The results of this in vitro study demonstrated that retentive values of the attachments tested are reduced significantly after initial placement; this reduction is not as large as reported previously by Breeding et al, and is more significant when the implants are not parallel. (Evtimovska, Masri et al. 2009)

The degree of resiliency provided by the attachments is another factor that must be considered. Available studies suggest that stud attachments provide varying degrees of resiliency in both vertical and horizontal directions. Attachment resiliency is associated with the movement between the abutment and the prosthesis in a predetermined direction or directions. The more directions in which the prosthesis can move, the less stress is placed on the implant, in turn, transferring more forces to the residual ridge. (Shafie 2006) Magnetic attachments provide no vertical resiliency, while quite effectively decreasing horizontal stress transmission to abutments. (Chung, Chung et al. 2004) On the other hand, Staubli believed that magnetic attachments provide no lateral stability and their use should be limited to selected cases. (Staubli 1996)

In regards to load distribution in different attachment systems, Menicucci et al. compared the stresses on the bone surrounding 2 implants using 2 anchorage devices for overdentures. His investigation found greater stress on peri-implant bone with a bar-clip attachment, compared with a ball attachment. The results of finite element model analysis showed that ball attachment favors load distribution onto the edentulous mucosa and the masticatory load is distributed over a wider area. Also, there was lower peri implant stress related to this type of attachment than the bar and clip. (Menicucci, Lorenzetti et al. 1998)

In regard to selection of a type of attachment for usage with implant-retained overdentures, several other factors are of importance. These attachments should be durable and easily replaced. Walton conducted a study on maintenance time and costs, adjustment and repair incidence and patient satisfaction in implant-retained overdentures, retained with either a bar with two clips or two ball attachments. He concluded that fabrication time, number of appointments and chair time for adjustment were similar for the two denture designs. According to this study, ball attachment dentures required about eight times longer for repairs than did the bar clip prosthesis, and significantly higher number of patients in the ball attachment group needed at least one repair per year compared to the bar clip group. Considering the equal level of patient satisfaction with both methods and higher number of repair appointments, he recommended that a bar clip design be used rather than ball attachment. (Walton, MacEntee et al. 2002)

Naert, in a prospective study, evaluated the prosthetic outcomes and patient satisfaction with ball attachments, magnets and bars. In this study, even though the bar group presented the highest retention capacity and the least prosthetic complication, there were more mucositis and gingival hyperplasia associated with this type. Patient satisfaction was similar for all three groups. (Naert, Gizani et al. 1999)

In a longitudinal prospective study by Bergendal et al. no difference in implant survival rate between bar-clip and ball attachments was found. (Bergendal and Engquist 1998)

Attachments and overdenture support

Controversy persists as to the influence of the design of the denture and the extension base contact of implant-retained overdentures on peri-implant stresses. The contact of the superstructure to the edentulous ridge may be as important as the type or number of anchorage system used. (Sadowsky and Caputo 2000) However, research has concentrated on the influence of various anchorage systems on stresses developed within supporting structures (implants) and less on the pressure transmitted to residual ridge under the prosthesis. (Meijer, Kuiper et al. 1992; Meijer, Starmans et al. 1993) Most of the studies conducted so far include direct measurement of stress under implants with photoelastic analysis or finite element analysis. Some studies have compared stress distribution under implant-retained overdenture with regards to different attachment systems. (el-Charkawi, Yehia et al. 1995; Ichikawa, Horiuchi et al. 1996; Kenney and Richards 1998; Porter, Petropoulos et al. 2002; Tokuhisa, Matsushita et al. 2003; Fanuscu and Caputo 2004) Ichikawa was one of the first to measure the load transfer to implant and soft tissue with different attachment systems. He used a model of mandible with two implants. The stress measuring gauges were embedded in the molar area of the edentulous ridge. The attachment systems were magnetic and ball attachment. He also had a group of modified magnetic systems. In this group, he placed silicone between magnet and denture base for a damping effect. The control group had no retainers and the implants were not in touch with the denture base. The study applied static and dynamic loads to lateral occlusal rims of the molar regions and measured the stresses applied to the ridge as well as strain formed around the implants. Based on the results, he concluded that occlusal stresses concentrated around the implant, especially in the areas distal to the implant. The attachment with the damping modifier provided optimal stress distribution. The influence of connecting structures during dynamic load application was less than that found during static loading. (Ichikawa, Horiuchi et al. 1996) Finite element analysis has been used to evaluate stresses on peri-implant bone in the edentulous mandible. (Meijer, Kuiper et al. 1992; Meijer, Starmans et al. 1993; Meijer, Starmans et al. 1993) Menicucci et al compared the stresses on the bone surrounding 2 implants using 2 anchorage devices for overdentures. His investigation found greater stress on peri-implant bone with a bar-clip attachment, compared with a ball attachment. The results of finite element model analysis showed that ball attachment favors load distribution onto the edentulous mucosa and the masticatory load is distributed over a wider area. Also there was lower peri implant stress related to this type of attachment than the bar and clip. (Menicucci, Lorenzetti et al. 1998) The same author has recently tried to measure the load transfers and pressure on the mucosa using load cells and strain-gauged abutments. (Menicucci, Ceruti et al. 2006) Kenney and Richards, using a photoelastic stress analysis also concluded that ball/O-ring attachments transferred less stress to implants than the bar-clip attachments when the model was subjected to a posterior vertical load. (Kenney and Richards 1998) However, in another study using piezoelectric transducer for 3-dimensional in vivo force measurements, overdentures were compared using single ball anchors or a splinted bar design on 2 mandibular implants. They found a general tendency of higher forces with solitary anchors and a positive effect of rigid bars for load sharing. (Mericske-Stern, Piotti et al. 1996)

Sadowsky and Caputo, paid attention to the relationship between extension base and load transfer. They conducted photoelastic experiments to analyze the load transfer characteristics of different mandibular-retained overdenture designs, including a cantilevered bar, spark erosion framework, non-cantilevered bar, and solitary anchors with and without ridge contact. Their results showed that without intimate extension base contact with the posterior edentulous ridge, the cantilevered anchorage systems generated the highest amount of stress, to the ipsilateral terminal implant. With simulated intimate extension base contact, all anchorage systems transferred low stress to the distal implant region. (Sadowsky and Caputo 2000) Another study by Sadowsky and Caputo focused only on cantilever design of the bar in a mandibular implant overdenture. The two cantilever designs were clip attachments and plunger-retained attachments. They concluded that both designs of cantilever demonstrated a low stress transfer to the ipsilateral and contralateral abutment, but the force distribution was more uniform on the plunger type. (Sadowsky and Caputo 2004)

Federick and Caputo, in a photoelastic study compared the simulated load transfer characteristics of mandibular overdentures with different attachment designs. They fabricated models of moderately atrophied edentulous mandible with 2 implants placed in the canine-first premolar region. They studied the load transfer with three attachment designs; resilient cap attachments, splinting bar, and bar with distal resilient caps. They found different load distribution characteristics with different retention designs, and a uniform distribution of force applied distal to the implants. They concluded that resilient cap direct attachment tended to provide the most uniform transfer of stress to the supporting structures. (Federick and Caputo 1996)

A few published studies on maxillary overdenture have compared the load transfer characteristics of 2 retention mechanisms in an implant-assisted maxillary palateless overdenture. Fanuscu placed four implants into a photoelastic model of a moderately resorbed edentulous maxilla and studied load transfer on two retention mechanisms. The retention mechanisms studies were bar with anterior clip and distal resilient attachments, solitary ball/O-ring attachments. Loads were applied to the palatal incline of central incisors and buccal incline of premolars. They concluded that protrusive loads were better distributed among the implants than the laterotrusive loads with both retention mechanisms. In their study, the O-ring system transferred bending forces to the implants under laterotrusive loads, especially to the loaded posterior implant. The bar-attachment system transferred high level stresses to the loaded posterior implant during laterotrusive loading. They also observed higher stress with O-ring system under laterotrusive loads at the distal edentulous ridge. (Fanuscu and Caputo 2004)

Furthermore, Mericske- Stern in an in vivo study on 2 implants observed that the anchorage system may have a more minor influence than is believed and other parameters such as superstructure fit and occlusion may also determine loading of implants. Mericske-Stern also stated in a more recent article that more information is needed regarding the effect of multiple implants (3 or 4) splinted with a bar in terms of force distribution. (Mericske-Stern 1998; Mericske-Stern 1998)

To summarize the contact of the superstructure to the edentulous ridge is as important as the type, distribution and the number of anchorage system used. (Sadowsky and Caputo 2000) So far, research has concentrated more on the influence of various anchorage systems on stresses developed within supporting structures (being the implants) and less on the pressure transmitted to residual ridge under the prosthesis. (Meijer, Kuiper et al. 1992; Meijer, Starmans et al. 1993; Meijer, Starmans et al. 1993) Most of the studies conducted to date include direct measurement of the stress under implants with photoelastic analysis or finite element analysis. Other studies have compared stress distribution under implant-retained overdentures with regards to different attachment systems. (el-Charkawi, Yehia et al. 1995; Ichikawa, Horiuchi et al.

1996; Kenney and Richards 1998; Porter, Petropoulos et al. 2002; Tokuhisa, Matsushita et al. 2003; Fanuscu and Caputo 2004)

In addition, most studies have focused on mandibular implant-retained overdentures and mostly on the load transferred to abutments, rather than measuring the pressure applied to the tissues. It is reasonable to conclude that with an increase in the number of implants, the responsibility for providing support and stability shifts from the mucosa to the implants. Misch believes that if enough implant support is provided, the resulting prosthesis may be completely supported, retained, and stabilized by the implants. (Misch 2005) This is clearly not only a function of the number of implants used, but also their distribution. It is conceivable that with usage of enough optimally distributed dental implants, the maxillary denture can be palateless. This would certainly simplify the treatment and increase the satisfaction level of the patient. It has been established that one of the reasons that patients with conventional maxillary dentures seek implant treatment is to have a palateless overdenture. (Ochiai, Williams et al. 2004)

There are several studies on the effect of the palate and the amount of the palatal coverage of maxillary dentures. (Strain 1952; Giddon DB 1954; Shannon, Terry et al. 1970; de Albuquerque Junior, Lund et al. 2000; Yeh, Johnson et al. 2000; Ochiai, Williams et al. 2004; Jivraj, Chee et al. 2006) Strain and Giddon have reported diminished taste with complete palatal coverage. (Strain 1952; Giddon DB 1954) Others report reduced salivary flow rate related to long term denture wearing. (Shannon, Terry et al. 1970; Yeh, Johnson et al. 2000) Severe gagging reflex or large palatal tori are other reasons why patients will seek palateless maxillary complete dentures. On the other hand, some authors have found no difference between patient responses to maxillary overdentures with or without palatal coverage. (de Albuquerque Junior, Lund et al. 2000)

Ochiai et al. conducted a photoelastic analysis of the effect of palatal support on several implant supported overdenture designs. The three different designs used in this study were all based on four implants and were as follows; a splinted Hader bar with 2 distal ERA and anterior clip, non-splinted Zaag attachments and nonsplinted Locator attachments. The stress analysis was done on all designs first with and then without palatal coverage. Analysis of data in this study showed the highest stress with the splinted Hader bar system followed by similar levels of stress with the other two designs. Removing the palatal coverage produced a greater load transfer effect and more concentrated stress difference around the supporting implants. The authors concluded that the incorporation of palatal coverage has a more important effect on reduction of stress than the design of the attachment system. Designs of more than four implants were not used in this study. (Ochiai, Williams et al. 2004)

As of the necessary number of implants needed for a maxillary implant-retained overdenture (IROD), the recommendations to this date are mostly empirical. It is reasonable to assume that as more implants are used to retain an overdenture, responsibility for providing support shifts from the mucosa to the implants and extended soft tissue coverage becomes less critical. It is yet to be determined if this shift in load distribution on the implants is advantageous or not. A systematic review of the available literature on maxillary implant-retained overdentures showed that there are no specific guidelines for the number of implants necessary to support a maxillary IROD. (Sadowsky 2007) Some authors have reported clinical success as determined by survival of prostheses and implants in treating patients with a palate-less IROD with a minimum of 4 supporting implants,(Lewis, Sharma et al. 1992; Naert, Quirynen et al. 1994; Mericske-Stern 1998; Kiener, Oetterli et al. 2001) while, others recommended the use of palatal coverage when 4or less implants are used.(Ochiai, Williams et al. 2004; Jivraj, Chee et al. 2006) It has also been reported that the design of 6 implants and a bar had the highest success rate, (Rodriguez, Orenstein et al. 2000) while others reported long-term success in treating patients with 4-6 unsplinted implants and reduced palatal coverage. (Cavallaro and Tarnow 2007)

Despite different recommendations on the number of implants used in an IROD, other complicating factors in the maxilla can affect the decision making about the sufficient number of implants in a palateless IROD. These factors include the lower quality of bone in the maxilla; (2) the muscles of mastication; (3) the type of dentition of the opposing arch and resulting occlusal forces; (4) the type and number of attachments; (5) the interarch distance; (6) the relationship between the shape of the residual ridge and form of the dental arch; and (7) Implant angulation.(Jivraj, Chee et al. 2006) These factors should be considered in decision making about the number and distribution of implants in an IROD.

None of the above recommendations so far has been supported by scientific records. It is reasonable to assume that the design or the distribution of the implants and the amount of the cantilever that will result has a direct impact on the pressure the overdenture exerts on the palate and hence, the amount of support that an overdenture must receive from the palate. No study has evaluated the relationship between pressure under a maxillary overdenture supported by four implants and the distribution of those implants. The current study is designed to understand the effect of anterior-posterior (AP) spread of the implants on force transmission to the palate.

PURPOSE

The purpose of this study was to determine how the anterior-posterior distribution of the implants supporting a maxillary four implant-retained overdenture would affect the amount of load transmitted to the palate.

NULL HYPOTHESIS

There is no difference in the amount of load transmitted to the palate in a four-implant supported overdenture, when the distance between the anterior and posterior implants increases from 8 to 16 and, 24 mm.

RESEARCH HYPOTHESIS

There is a significant reduction in the amount of pressure transmitted to the palate in a four-implant supported maxillary overdenture when the distance between the anterior and posterior implants increases from 8 to 16, and 24 mm.

MATERIAL AND METHODS

Fabrication of the oral analog

An analog of the edentulous maxilla was fabricated using a model former of an edentulous maxillary ridge with moderate resorption (Columbia Dentoform Corp, model V50, New York, NY). Autopolymerizing acrylic resin (Jet Acrylic; Lang MFG Co, Wheeling, IL) was mixed, and poured into the model former. After the acrylic resin polymerized, a coarse lab carbide bur (#H79G, Brasseler; Savannah, GA) was used to prepare 8 holes in the areas of maxillary canines, premolars and first molars. Each hole was large enough to house an implant analog (Nobel Replace Select, internal hex, regular platform, 4.3 × 13 mm, Nobel Biocare, Yorba Linda, CA). Using a surveyor (Ney Dental International, Bloomfield, CT) and guide pins, eight parallel implant analogs were placed inside the prepared holes and were fixed using autopolymerizing acrylic resin (Lang MFG Co, Wheeling, IL). Analogs in the area of canines were 26 mm apart, and 12 mm posterior to the most anterior part of the edentulous ridge (Figure 1). The distance between the center of analogs inserted in the canine areas and analogs inserted in the first premolar areas was 8 mm, center to center. The same 8 mm distance was maintained between the centers of the remaining implant analogs on each side. The platform of all the implant analogs was placed 1 mm below the surface of the simulated maxillary ridge (Figure 2). For the purpose of this study, these analogs were named by the tooth number at the location as #3, 4, 5, 6, 11, 12, 13 and 14. The hamular notches were marked on the analog and connected using a pencil. The area of the posterior palatal seal was scored on the surface of the analog (Figure 2).

To simulate the oral environment and imitate the resiliency of maxillary soft tissues on the analog, a 4 mm thick layer from the surface of the oral analog was removed using a carbide bur (#H77E, Brasseler; Savannah, GA) and replaced with rubber gingival material (Gingival Mask HP; Henry Schein Inc, Melville, NY). To ensure that a 4 mm uniform layer was removed, depth grooves were carved on the surface of the oral analog using a carbide bur (#H129E, Brasseler; Savannah, GA). Using the same bur, 3 escape grooves, 4×4 mm, were carved on the sides of the oral analog to provide space for excess rubber gingival material to flow. After reduction, the surface of the model former was lightly lubricated with petroleum jelly (Swan; Perrigo, Allegan, MI). A uniform layer of gingival mask material was injected on the surface of the oral analog. The oral analog was seated back inside the model former while caution was exercised to make sure that the base of the analog was level with the surface of the model former. Excess gingival mask material covering the dental implant analogs was removed using #11 scalpel (Becton Dickinson; Hancock, NY) (Figure 3).

According to studies (Kydd, Daly et al. 1971; Studer, Allen et al. 1997; Muller, Schaller et al. 2000; Wara-aswapati, Pitiphat et al. 2001; Schacher, Burklin et al. 2010), the thickness of the palatal mucosa is variable depending on age, sex and location of the measurement on the palate. In general the mean reported thickness of the palatal masticatory mucosa in those studies, ranges between 2.4 ± 0.7 to 5.11 ± 1.07 mm. Previous in vitro studies performed on oral analogs have used a thickness of 4 mm of stimulated mucosa which is within the range of in vivo findings. (Masri, Driscoll et al. 2002; Al-Ahmad, Masri et al. 2006) Therefore, a thickness of 4 mm was used for the purpose of this study.

Fabrication of the custom trays

The female parts of the Locator attachments (Zest Anchors INC, Escondido, CA) (Figure 4) were attached to the implants on the oral analog using the abutment driver part of the attaching tool (Locator Core Tool, Zest Anchors INC, Escondido, CA) and torqued to 30 N/Cm with a wrench (Locator Torque Wrench; Zest Anchors INC, Escondido, CA) per manufacturer's recommendation. Two layers of baseplate wax (TruWax, Dentsply, York, PA) were placed on the oral analog and using light polymerized custom tray material (Triad custom tray material, Dentsply, York, PA), 15 custom trays were fabricated and polymerized for 4 minutes in a curing unit (2000 Visible Light curing Unit, Dentsply, York, PA). Afterwards, the internal surfaces of the custom trays were polymerized using the same technique, off the analog. The custom trays were made 2 mm short of the vestibule, but in order to ensure a controlled pressure during impression making, they were left long enough in three 3 spots (stops) to contact the acrylic resin of the vestibule of the oral analog. The positions of the stops were 1 in the anterior and the other 2 in the areas of the hamular notches to provide a tripod stopping effect.

The custom trays were lightly coated with vinyl polysiloxane (VPS) adhesive (Caulk tray Adhesive; Dentsply, Milford, DE) and air-dried for 24 hours. The surface of the oral analog was lubricated with petroleum jelly (Swan; Perrigo, Allegan, MI) and 15 final impressions were made using VPS impression material (Aquasil Monophase ®; Dentsply, Milford, DE). These impressions were boxed with boxing wax (Dentsply Boxing Wax; Dentsply, York, PA) and poured in vacuum mixed type III dental stone (Denstone Golden; Heraeus Kulzer, South Bend, IN).

Fabrication of occlusal rims

One layer of light polymerized denture base material (Triad pink unfibered denture base material; Dentsply, York, PA) was adapted over each record base and light polymerized for 4 minutes. A wax rim (TruWax; Dentsply, York, PA) was adapted and secured over the record base, using wax (Sticky Wax; Kerr Corp, Romulus, MI). The dimension of the wax rim was 34 × 8 × 8 mm. A putty (Lab Putty; Coltene/Whaledent, Cuyahoga Falls, OH) index of this occlusal rim was made and used to fabricate similar occlusal rims for the remaining 14 denture bases. The dimensions of the rims corresponded to an average sum of first and second premolars and molars.(Ash and Nelson 2003) The exact location of the rims was marked and measured on one base to produce the same location on the others.

Fabrication of the denture bases

The record bases were placed on the casts and their borders were sealed with melted baseplate wax (TruWax, Dentsply, York, PA). The casts were invested in the drag of the denture processing flasks (Teledyne Hanau Processing Flask, Buffalo, NY), using Type II dental plaster (Modern Material Dental Plaster, Heraeus Kulzer, South Bend, IN). The undercuts in the investment were removed and the investment was allowed to set. A thin layer of separating medium (Modern Material Separating Medium, Heraeus Kulzer, South Bend, IN) was applied to the surface of the investment. The cope was positioned in place and a second mix of Type II plaster was poured into the flask until the ring was filled completely and the top placed in position. The flasks were placed in a boil-out tank for 8 minutes (Nevin Laboratories, Chicago, IL) to eliminate the wax. The remaining wax was rinsed with hot running water after separating the cope and drag. A layer of separating medium (Modern Material Separating Medium, Heraeus Kulzer, South Bend, IN) was applied to the plaster of the investment in both portions and allowed to cool.

Heat polymerized polymethylmethacrylate resin (Lucitone 199; Dentsply, York, PA) was mixed according to manufacturer’s instructions and packed in the doughy stage at 1500 psi for 3 trial packs (Nevin Pneumatic Press Unit; Nevin Laboratories, Chicago, IL) using 4×4 clear separating sheets (.001” thick) (Densilk, Reliance Dental Mfg. Co., Worth, Il) soaked in water as a separator, and at 3000 psi for one final pack. The flasks were clamped (Hanau Flask Compress; Buffalo, NY) and polymerized at 165 degrees F (74 degrees C) for 9 hours from the time of initial placement into the denture curing unit (Nevin 4900 Electronic Denture Curing system; Nevin Laboratories, Chicago, IL). After allowing enough time for bench cooling, the 2 parts of the flasks were separated. The denture bases were retrieved, finished, and polished (Figure 5).

The intaglio of the denture bases were painted with pressure indicating paste (Mizzy Pressure Indicating Paste; Keystone Industries, Cherry Hill, NJ) and adjusted with carbide bur to insure intimate contact of the palate and the ridge to the denture base.

Activating the attachments

Relief holes corresponding to each Locator were made on denture bases using a #8 acrylic round bur (Brasseler, Savannah, GA) to make sufficient room for the male part of the Locator attachments. The Locator Housings (Figure 4) with black male processing attachments were placed on each Locator of the analog and white spacers were placed around the female part to prevent the acrylic from locking in. Using autopolymerizing acrylic resin, the male parts were picked up in the denture bases. The black processing attachments were replaced by extra-light blue male attachments using a tool (Locator Core Tool; Zest Anchors Inc. Escondido, CA). The retention of the blue male attachment is 1.5 lb, which is the lightest among the three attachments. The other two colors of male attachments available are pink (3 lb) and clear (5 lb).

Testing procedure

The Locator abutments were removed from the oral analog and a force measuring sensor (Flexiforce, Tekscan, South Boston, MA) was placed in the middle of the palatal area of the original maxillary analog. The standard Flexiforce sensor is a 14 mm diameter circle with a thickness of 0.127 mm (Figure 6). The active sensing area of the sensor has a diameter of 10 mm. The sensor was calibrated using known weights and then secured to the palate of the analog by applying a very small amount of adhesive (Zip Dry Paper Glue, Beacon Adhesive Company, Mt Vernon, NY) to the shaft area of the sensor (Figure 6). Caution was exercised not to apply adhesive to the sensor area. The outline of the sensor was marked with pencil on the analog in order to mark the exact location in case the sensor needed to be changed (Figure 6). Experimental denture bases were seated over the maxillary analog. A perpendicular static load of 245 N was applied bilaterally, to the occlusal rims of the denture bases, using a universal testing machine (Satec Material Testing Equipment, T 5000 Series, Scottsdale, AZ) for a period of 60 seconds to ensure that the applied forced reached a stable continuous level that can be recorded accurately. The oral analog and overlying denture base were carefully positioned in the center of the platform of the testing machine so that the upper member of the universal testing machine contacted both sides of the denture base simultaneously (Figure 7).

Previous in vitro investigations applying load on maxillary overdentures, have used a static force of 100-110 N to simulate occlusal force. (Porter, Petropoulos et al. 2002; Ochiai, Williams et al. 2004; Akca, Akkocaoglu et al. 2007) It appears that in these studies the amount of occlusal force applied was determined arbitrarily. The maximum bite force in patients with overdentures has been shown to range between 120-375 N in different studies (van Kampen, van der Bilt et al. 2002) (Rismanchian, Bajoghli et al. 2009). In this study, the force used (245 N) was well within the range of the masticatory force reported for overdenture wearers.

Data from the force-measuring sensor were collected using a laptop computer and a computer software (ELF Flexiforce; Tekscan, South Boston, MA), and the peak force measured on the palate was recorded. For this study six different designs for location and distribution of Locator attachments were used. Three of these designs were the experimental groups, tended to explore the load under the overdenture with different distribution of four Locator attachments. They were as following:

- After inserting the Locators on implants in the areas of canines and first premolars (4 Locators with 8 mm distance, Group 4a)
- After inserting the Locators on implants in the areas of canines and second premolars (4 Locators with distance 16 mm, Group 4b)
- After inserting Locators on implants in the areas of canines and first molars (4 Locators with distance 24 mm, Group 4c)

The other three designs (control) were used to compare the experimental conditions to designs with less or more than four Locator attachments. These included:

- Without the insertion of Locators (group 0)
- After inserting 2 Locators on implants only in the areas of canines (group 2)
- After inserting all 8 Locators (group 8)

Each denture base was tested with all 6 variations described in Table 1. The order of the tests was randomly assigned using a computer software (Excel 2007; Microsoft, Redmond, WA).

Data analysis and statistics

The load on the palate was recorded for all experimental groups and statistical analysis was completed using a one-way Analysis of Variance (ANOVA) and Tukey's Honestly Significant Difference Test (HSD) for multiple comparisons. A p value of <0.05 was considered significant. Leven's test was used to verify homogeneity of variances. Results are reported in Newtons as mean and standard deviation ranges (SD).

RESULTS

The results of this study reject the null hypothesis that there is no significant difference in the amount of force transmitted to the palate in a four-implant supported overdenture, when the distance between the anterior and posterior implants increases from 0 to 8,16,24 mm. The distance between, and distribution of, implants had significant effects on the load transmitted to the palate in an overdenture supported by Locators ($F=17.6$, $p<0.0001$, Table 2). Using Levene's statistics (1.359), there was no significant difference between the variances in the 6 groups ($p=0.248$), therefore the use of ANOVA was legitimate. The results of the Tukey's HSD are summarized in Figure 8.

Load transmitted to the palate ranged from 20.67 +/- 16.06 N (mean +/- SD) for overdentures supported by 8 Locators to 85.61 +/- 27.94 N for a conventional denture (control). The load transmitted to the palate by the control groups (0 and 2); conventional denture group and overdentures supported by two Locator attachments were significantly higher than all other groups (Figure 8, Table 2). The amount of load transmitted to the palate when the overdentures were supported by 4 Locator attachments, irrespective of the distance between the implants was significantly lower than when no or when two

Locator attachments were used. However, they were not significantly different from each other (Figure 8). When the overdentures were supported by 8 locator attachments (control group number 8), the load transmitted to the palate was significantly lower than that of conventional dentures, overdentures supported by 2 Locator attachments and overdentures supported by 4 Locator attachments when the distance between the anterior and posterior implants was 8 mm. Table 3 demonstrates the mean percentage of load transmitted to the palate, for each group of overdentures. The percentage values are obtained by dividing the mean load values by 245 (total occlusal force exerted). Examples of palatal load recorded under the dentures from each group are presented in Figure 9-1 to 9-6. These figures demonstrate the amount of load transmitted to the palate from the moment of application of the compressive force, to the moment when the force reaches a maximum of 245 N and is continued for 60 seconds. The highest point of each line in the graph represents the peak load transmitted to the palate in N.

DISCUSSION

The results support the null hypothesis, as there was not a significant difference in the amount of load transmitted to the palate in a four-implant supported overdenture, when the linear distance between the anterior and posterior implants increases from 8 to 16, and 24 mm.

The distance between, and distribution of implants did not have a significant effects on the load transmitted to the palate in an overdenture supported by 4 Locators.

The hard palate in a maxillary denture is the primary supporting area and it is generally used to provide support for dentures.(Boucher 1951) The results of this in vitro study suggest that when 4 or more implants are used, the support for the overdenture is primarily provided by the implants rather than the palate. This conclusion is based on the assumption that force measured on the palate is transferred solely to the supporting tissues and that remaining forces are transmitted to the implants. However, the load transmitted to the implants remains to be determined and should be measured directly.

In the current study, when no implants were used (control group), approximately 35% (85.61 N out of 245 N applied) of the load was transmitted to the palate. When only 2 implants were used, the amount of load on the palate, slightly declined, but this reduction was not significant (approximately 31%). These results indicate that even though 2 implants may provide a maxillary implant retained overdenture with acceptable retention, the hard palate considerably contributes to the support for the overdenture.

When 4 implants with minimum distance in between (8mm) were used, the load transmitted to the palate significantly dropped from 35% with no implants to 20%, showing that support for the 4 implant-retained overdenture is provided primarily by the implants and to a lesser degree by the palate. When the distance between the 4 implants increased to 16 and 24 mm, the mean load transmitted to the palate, significantly declined to 28.4 and 35.67 N respectively (11 and 16%).

When 8 implants were used, only about 8% of load (20.7 N) was transmitted to the palate, but this load was not significantly lower than when 4 implants with a distance of 16 and 24 were used. These results indicate that the palatal portion of overdentures doesn't contribute significantly to load distribution when 4 implants, with a distance of more than 16 mm are used.

An interesting observation is that the force transmitted to the palate in the situation with 24 mm distance was slightly higher than when 16 mm distance was used. Although this was not statistically significant, but one plausible explanation to the phenomenon is that as the anteroposterior distance between the implants increases, but the number of implants utilized does not increase, the resiliency of the denture base can contribute to more force transmission to the palate.

Based on finite element analysis and photoelastic studies and empirical experiences, it has been recommended that at least 6 implants should be used if a palateless denture is to be fabricated. (Rodriguez, Orenstein et al. 2000; Jivraj, Chee et al. 2006) In general, it is a common assumption that when using 6 or more implants the support for the complete maxillary overdenture is provided by the implants. This in vitro investigation is a first step in exploring the feasibility of eliminating the palate when only 4 independent non-splinted implants are used.

It should be kept in mind that in the oral cavity, stress distribution and success of an IROD are affected by many factors other than the implant distribution and type/design of the attachment systems used. These include: (1) the poor quality of bone in the maxilla; (2) the muscles of mastication; (3) the type of dentition of the opposing arch and resulting occlusal forces; (4) the type and number of attachments; (5) the interarch distance; (6) the relationship between the shape of the residual ridge and form of the dental arch; and (7) Implant angulations.(Jivraj, Chee et al. 2006) These factors should be considered in decision making about the number and distribution of implants in an IROD.

Ochiai and collaborators performed a photoelastic study on three attachment designs, with and without palate and concluded that removal of the palatal support produced greater load transfer effect and more concentrated stress around the implants. They concluded that incorporation of the palate may be more important than the attachment system used. They studied implant-retained overdentures, retained by a) splinted bar, b) 4 Locators, and c) Zaag attachments. In their article, they did not specify the anteroposterior distribution of the implants and therefore, we cannot directly compare their results with the results of the current study. (Ochiai, Williams et al. 2004).

The current study is an in vitro study and did not exactly mimic the oral environment. In this study, only perpendicular forces were applied on the rims. The effect of dynamic masticatory forces on anatomic cusps that will result in a nonaxial vector, was not evaluated .The amount of force transmitted to the palate (and/or the implants), maybe influenced by the direction of force. Further, the long-term effects of attachment fatigue and wear on the force transmission to the palate were not assessed. Although, a prediction that prolonged denture use is associated with bone resorption and as bone resorbs, the dentures become ill fitting and the forces are more likely to be transmitted to the implants. It is noteworthy to mention that this situation is more likely encountered in the maxilla without implant support. Bone resorption is relatively small in the palatal portion of the denture bearing area. Therefore, support from the palate likely stabilizes and limits the instability resulting from bone resorption in the alveolar ridge.

In the present study denture bases were adjusted before the experiment to insure initial positive seat and contact with the hard palate of the oral analog. The resiliency of the vinyl polysiloxane soft tissue mimicking material used may not accurately replicate the resiliency of oral mucosa. Also, different locations on the palate may have different resiliencies that can affect the in vivo results. In addition, the experiment was conducted on a moderate size maxillary analog (45 mm anteroposterior length), and the results on a larger or smaller maxilla could be different. Further, the analogs were placed parallel to each other and the effect of the angulated implants was not tested.

As mentioned before, it has been demonstrated that using a splinted implant design might have a negative impact on the stress concentration on the implants and the crestal bone. (Menicucci, Lorenzetti et al. 1998) Whether or not a splinted design of implants has an effect on the results of this study was not evaluated here. Other methods of studying the load transfer, such as incorporation of stress gauges around the implants, or photoelastic models, can render a clearer view of the load distribution pattern and thus, better treatment planning decisions. The above mentioned are among the limitations of the study and can be ground for further tests.

These caveats notwithstanding, the results of this in vitro study demonstrate that the number and distribution of implants affect the forces measured on the palatal area of an average sized edentulous oral analog.

CONCLUSION

Within the limitations of this study, using 4 Locator attachments produced significantly less load on the palate, compared to when zero or two Locators were used. There was not a significant reduction in the load when the distance between the four Locator attachments increased from 8 to 24 mm. The use of 8 Locators produced the least amount of load on the palate, but this was not significantly lower than the situations where four Locators with a distance of 16 or 24 mm were used.

TABLE 1

ASSIGNED GROUP NUMBERS

Group Number	Number And Distance of Locators
0	No Locators
2	Two Locators
4a	4 Locators with 8 mm anteroposterior distance
4b	4 Locators with 16 mm anteroposterior distance
4c	4 Locators with 24 mm anteroposterior distance
8	8 Locators

TABLE 2

ANOVA TABLE OF MEAN LOAD VALUES

Groups	N	Mean	S.D.	F	p
0	14	85.61 a*	27.9	17.609	0.0001
2	15	76.07 a	27.6		
4a	15	49.84 b	26.5		
4c	15	35.66 bc	21.2		
4b	15	28.40 bc	22.9		
8	15	20.67 c	16.1		

*** Means marked with the same letter are not significantly different**

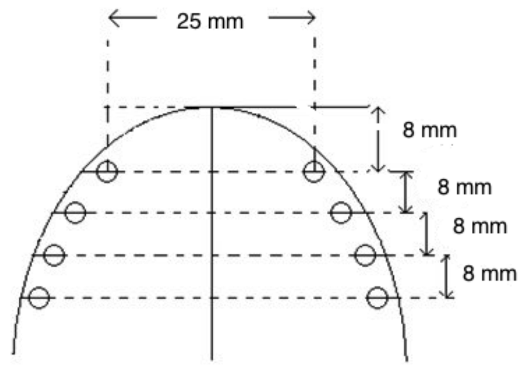
TABLE 3

PERCENTAGE OF THE TOTAL LOAD TRANSMITTED TO THE PALATE

Groups	Percentage of load
0	35%
2	31%
4a	20%
4c	16%
4b	11%
8	8%

FIGURE 1

DISTRIBUTION OF IMPLANT ANALOGS



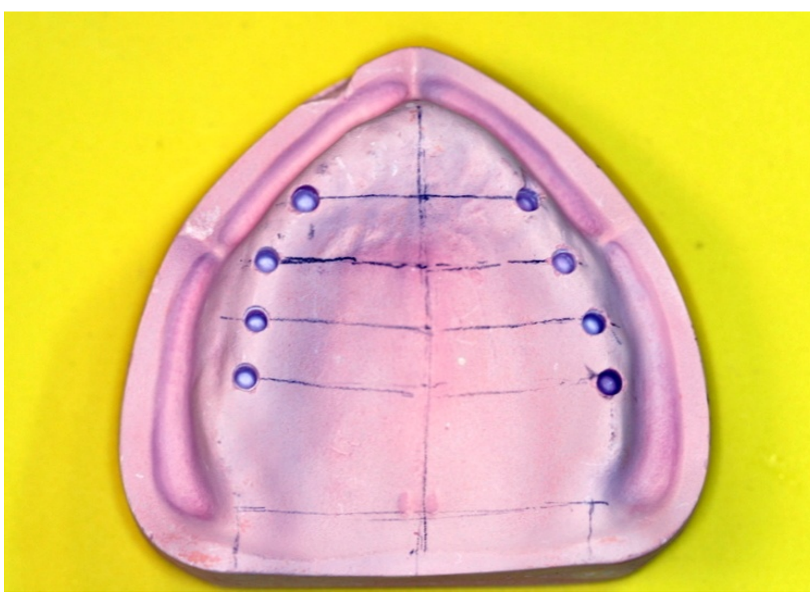


FIGURE 2

LOCATION OF IMPLANT ANALOGS TO THE SURFACE AND TO EACH OTHER

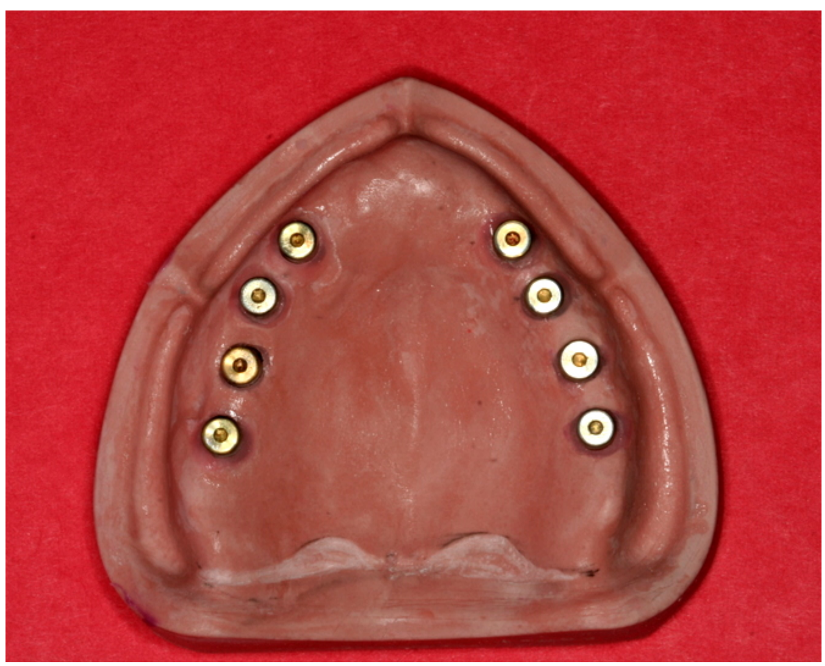


FIGURE 3

COMPLETED MAXILLARY ANALOG WITH SOFT TISSUE SUBSTITUTE

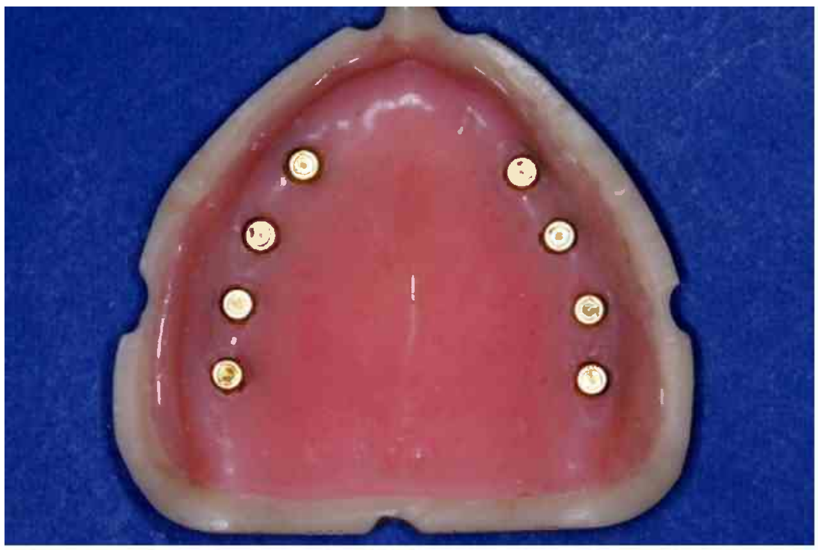


FIGURE 4

LOCATOR ATTACHMENT

FEMALE PART OF LOCATOR ATTACHMENT AND METAL HOUSING

THREE PARTS OF LOCATOR ATTACHMENT

FIGURE 5

FINAL DENTURE BASE WITH OCCLUSAL RIMS

FIGURE 6

FLEXIFORCE SENSOR AND LOCATION ON THE PALATE

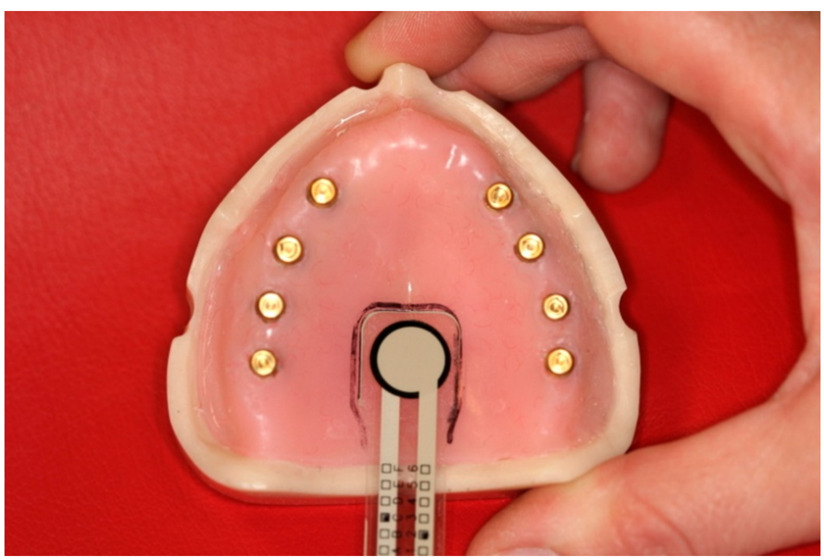
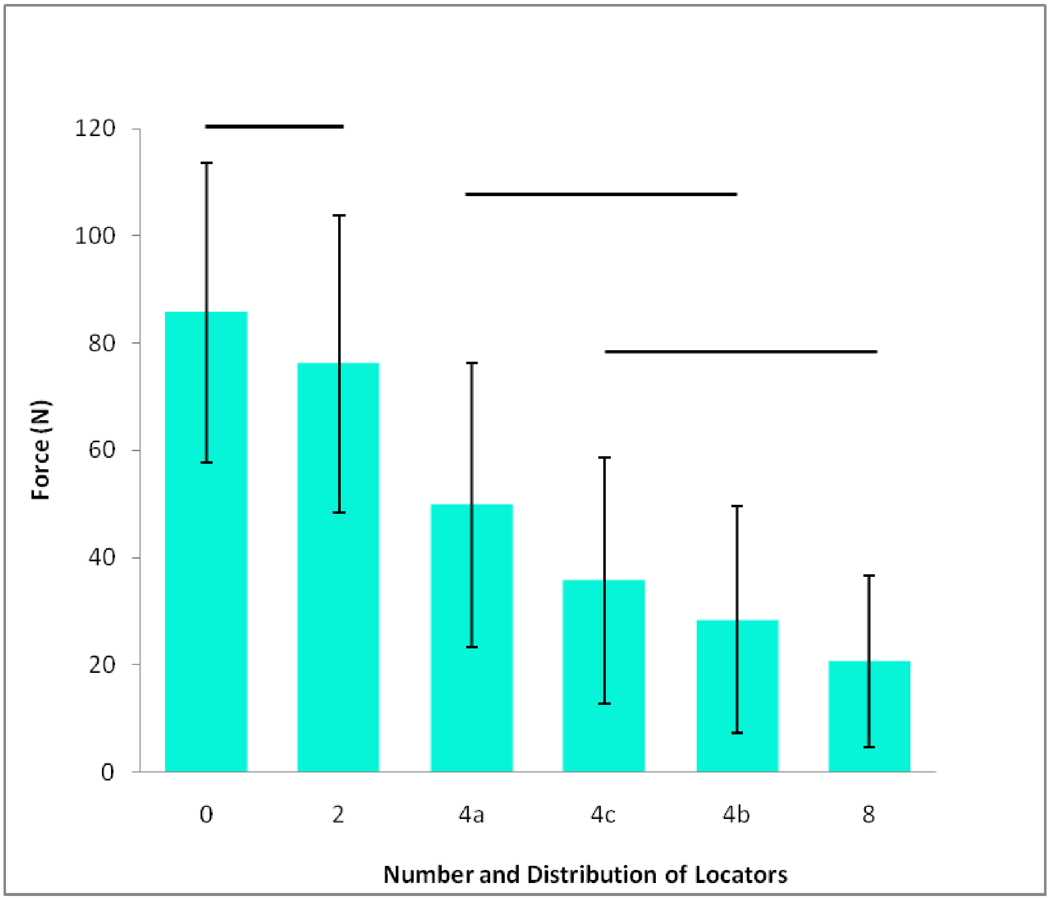


FIGURE 7

APPLICATION OF FORCE USING SATEC MACHINE

FIGURE 8

MEAN LOAD (FORCE) ON THE PALATE FOR EACH GROUP OF DENTURES



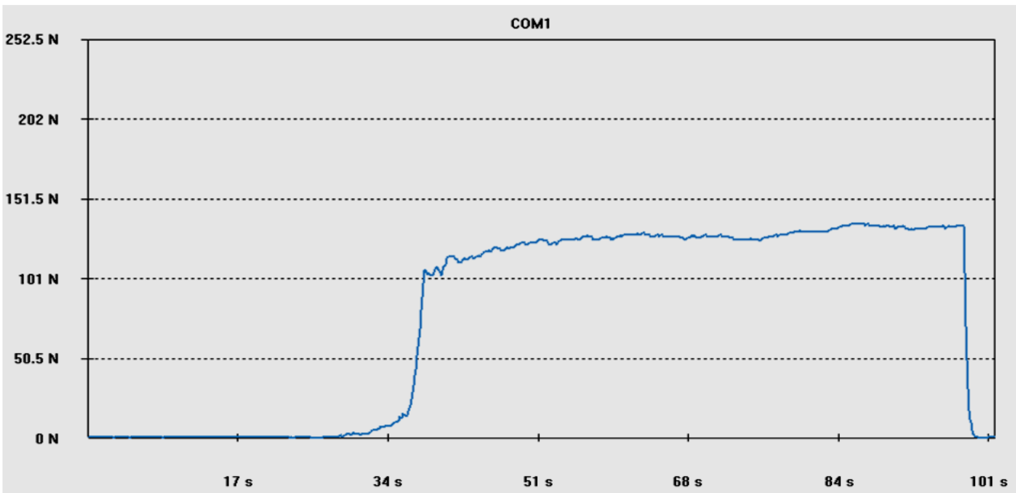
Groups connected with the same line are not statistically significant (F=17.61, P<0.0001)

FIGURE 9

EXAMPLES OF PALATAL LOAD RECORDED UNDER OVERDENTURE DURING 60 Sec of 245 N force (SAMPLE NUMBER 2)

Figure 9-1

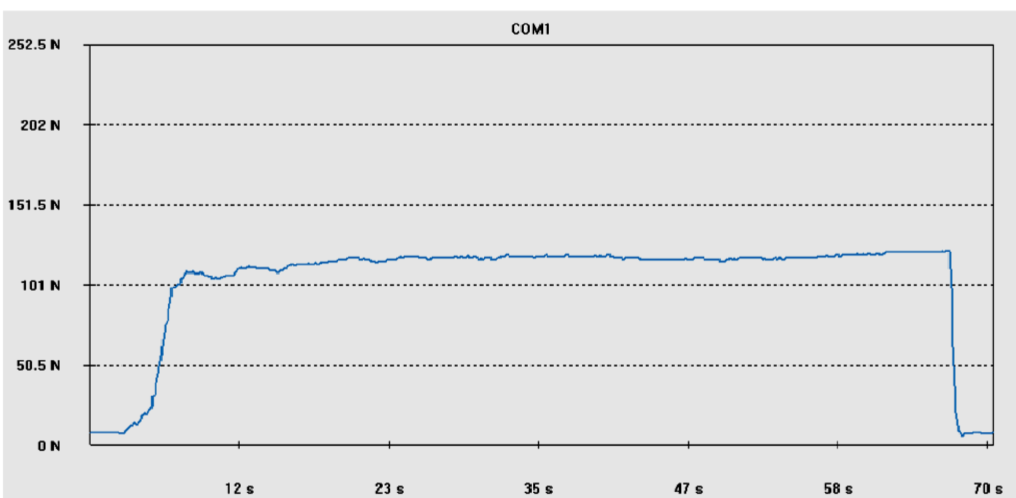
Group 0; 0 Locators



Peak stress: 135.6 N

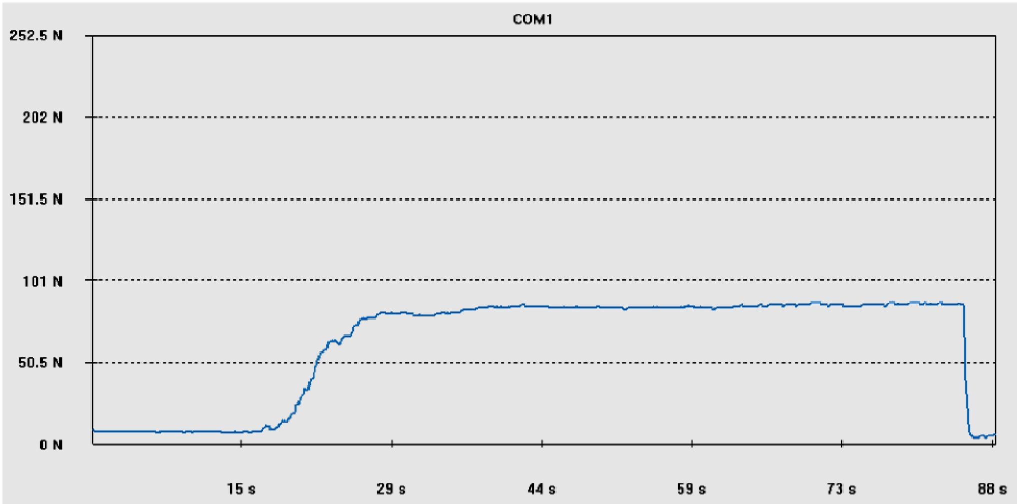
Figure 9-2

Group 2, 2 Locators



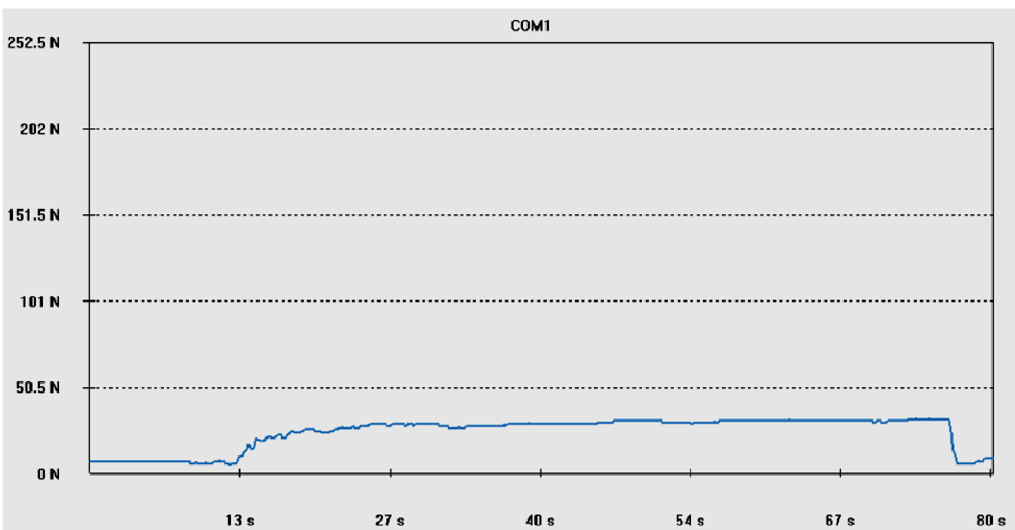
Peak stress: 122.8 N

Figure 9-3
Group 4a, 4 Locators with 8mm distance



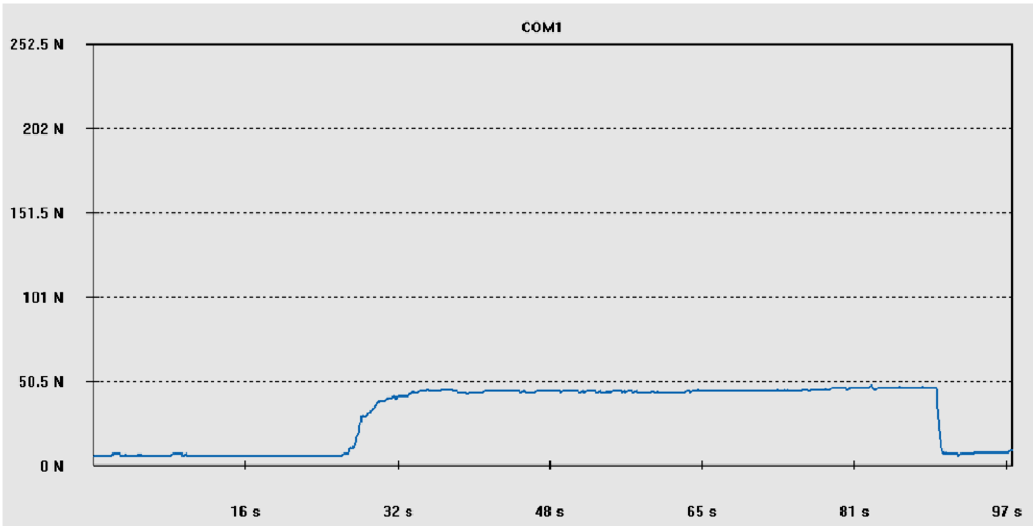
Peak stress: 87.1 N

Figure 9-4
Group 4b, 4 Locators with 16 mm distance



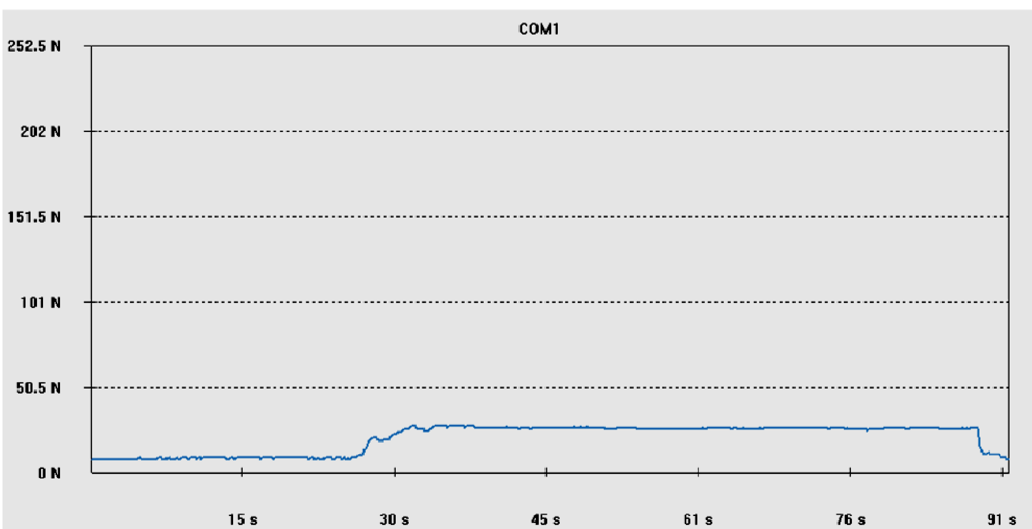
Peak stress: 31.7 N

Figure 9-5
Group 4c, 4 Locators with 24 mm distance



Peak stress: 47.5 N

Figure 9-6
Group 8, 8 Locators



Peak stress: 27.7 N

Appendix 1

Data and Statistical Analysis

Peak load results in Newton

	0 Implants (N)	2 Implants (N)	4 implants-8mm distance (N)	4 implants -16 mm distance (N)	4 implants-24 mm distance (N)	8 Implants (N)
Denture#1		101.009	91.79071	29.61623	32.65631	25.69355
Denture #2	135.6267	122.7799	87.0835	31.67564	47.46443	27.65489
Denture #3	93.06558	96.98826	60.31121	19.71147	16.76946	9.8067
Denture #4	92.08491	84.14149	45.50309	25.69355	33.63698	19.71147
Denture #5	87.0835	42.56108	17.75013	10.88544	11.86611	5.88402
Denture #6	108.8544	98.9496	53.44652	36.57899	38.54033	22.75154
Denture #7	79.14007	74.23672	56.38853	57.3692	58.34987	35.59832
Denture #8	102.9704	46.48376	17.75013	11.86611	11.86611	7.84536
Denture #9	89.04484	87.0835	78.1594	48.4451	69.2353	30.69497
Denture #10	77.17873	68.25463	42.56108	23.73221	37.55966	19.71147
Denture #11	106.893	96.00759	80.12074	84.14149	78.1594	67.27396
Denture #12	52.46585	33.63698	20.7902	9.8067	12.84678	7.84536
Denture #13	15.78879	33.63698	25.69355	8.82603	12.84678	6.86469
Denture #14	73.25605	59.33054	14.80812	11.86611	11.86611	9.8067
Denture #15	85.12216	96.00759	55.40786	15.78879	61.29188	12.84678
Mean	85.61249	76.07384	49.83765	28.4002	35.6637	20.66599
Standard Deviation	27.93831	27.63311	26.52206	21.16809	22.93761	16.05984

Data and Statistical Analysis (Continued)

Oneway ANOVA

Notes

Output Created		02-Mar-2010 10:29:37
Comments		
Input	Active Dataset	DataSet0
	Filter	<none>
	Weight	<none>
	Split File	<none>
	N of Rows in Working Data File	90
Missing Value Handling	Definition of Missing	User-defined missing values are treated as missing.
	Cases Used	Statistics for each analysis are based on cases with no missing data for any variable in the analysis.
Syntax		ONEWAY Newtons BY group /STATISTICS DESCRIPTIVES HOMOGENEITY /MISSING ANALYSIS /POSTHOC=TUKEY ALPHA(0.05).
Resources	Processor Time	00:00:00.016
	Elapsed Time	00:00:00.064

[DataSet0]

Data and Statistical Analysis (Continued)

Descriptives

Newtons

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
0 locators	14	85.6121	27.93746	7.46660	69.4815	101.7428	15.79	135.63
2 locators	15	76.0740	27.63325	7.13487	60.7712	91.3768	33.64	122.78
4 locators, 8 mm distance	15	49.8373	26.52182	6.84790	35.1500	64.5246	14.81	91.79
4 locators, 16 mm distance	15	28.4000	21.16898	5.46581	16.6770	40.1230	8.83	84.14
4 locators, 24 mm distance	15	35.6647	22.93542	5.92190	22.9635	48.3659	11.87	78.16
8 locators	15	20.6653	16.05827	4.14623	11.7726	29.5581	5.88	67.27
Total	89	48.9684	33.50379	3.55139	41.9108	56.0261	5.88	135.63

Test of Homogeneity of Variances

Newtons

Levene Statistic	df1	df2	Sig.
1.359	5	83	.248

ANOVA

Newtons

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	50847.403	5	10169.481	17.609	.000
Within Groups	47932.948	83	577.505		
Total	98780.351	88			

Post Hoc Tests Table

Multiple Comparisons

Newtons

Tukey HSD

(I) group	(J) group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
0 locators	2 locators	9.53814	8.93033	.893	-16.5148	35.5911
	4 locators, 8 mm distance	35.77481*	8.93033	.002	9.7218	61.8278
	4 locators, 16 mm distance	57.21214*	8.93033	.000	31.1592	83.2651
	4 locators, 24 mm distance	49.94748*	8.93033	.000	23.8945	76.0005
	8 locators	64.94681*	8.93033	.000	38.8938	90.9998
2 locators	0 locators	-9.53814	8.93033	.893	-35.5911	16.5148
	4 locators, 8 mm distance	26.23667*	8.77501	.041	.6368	51.8365
	4 locators, 16 mm distance	47.67400*	8.77501	.000	22.0741	73.2739
	4 locators, 24 mm distance	40.40933*	8.77501	.000	14.8095	66.0092
	8 locators	55.40867*	8.77501	.000	29.8088	81.0085

4 locators, 8 mm distance	0 locators	-35.77481*	8.93033	.002	-61.8278	-9.7218
	2 locators	-26.23667*	8.77501	.041	-51.8365	-.6368
	4 locators, 16 mm distance	21.43733	8.77501	.154	-4.1625	47.0372
	4 locators, 24 mm distance	14.17267	8.77501	.591	-11.4272	39.7725
	8 locators	29.17200*	8.77501	.016	3.5721	54.7719
4 locators, 16 mm distance	0 locators	-57.21214*	8.93033	.000	-83.2651	-31.1592
	2 locators	-47.67400*	8.77501	.000	-73.2739	-22.0741
	4 locators, 8 mm distance	-21.43733	8.77501	.154	-47.0372	4.1625
	4 locators, 24 mm distance	-7.26467	8.77501	.962	-32.8645	18.3352
	8 locators	7.73467	8.77501	.950	-17.8652	33.3345
4 locators, 24 mm distance	0 locators	-49.94748*	8.93033	.000	-76.0005	-23.8945
	2 locators	-40.40933*	8.77501	.000	-66.0092	-14.8095
	4 locators, 8 mm distance	-14.17267	8.77501	.591	-39.7725	11.4272
	4 locators, 16 mm distance	7.26467	8.77501	.962	-18.3352	32.8645
	8 locators	14.99933	8.77501	.530	-10.6005	40.5992
8 locators	0 locators	-64.94681*	8.93033	.000	-90.9998	-38.8938
	2 locators	-55.40867*	8.77501	.000	-81.0085	-29.8088
	4 locators, 8 mm distance	-29.17200*	8.77501	.016	-54.7719	-3.5721
	4 locators, 16 mm distance	-7.73467	8.77501	.950	-33.3345	17.8652
	4 locators, 24 mm distance	-14.99933	8.77501	.530	-40.5992	10.6005

*. The mean difference is significant at the 0.05 level.

Homogeneous Subsets

Tukey HSD

group	N	Subset for alpha = 0.05		
		1	2	3
8 locators	15	20.6653		
4 locators, 16 mm distance	15	28.4000	28.4000	
4 locators, 24 mm distance	15	35.6647	35.6647	
4 locators, 8 mm distance	15		49.8373	
2 locators	15			76.0740
0 locators	14			85.6121
Sig.		.536	.158	.888

Means for groups in homogeneous subsets are displayed.

REFERENCES

Adell, R., U. Lekholm, et al. (1981). "A 15-year study of osseointegrated implants in the treatment of the edentulous jaw." Int J Oral Surg 10(6): 387-416.

Akca, K., M. Akkocaoglu, et al. (2007). "Bone strains around immediately loaded implants supporting mandibular overdentures in human cadavers." Int J Oral Maxillofac Implants 22(1): 101-109.

Al-Ahmad, A., R. Masri, et al. (2006). "Pressure generated on a simulated mandibular oral analog by impression materials in custom trays of different design." J Prosthodont 15(2): 95-101.

Ash, M. M. and S. J. Nelson (2003). Wheeler's dental anatomy, physiology and occlusion. Philadelphia, Saunders.

Atwood, D. A. (1971). "Reduction of residual ridges: a major oral disease entity." J Prosthet Dent 26(3): 266-279.

Atwood, D. A. (2001). "Some clinical factors related to rate of resorption of residual ridges. 1962." J Prosthet Dent 86(2): 119-125.

Augsburger, R. H. (1966). "The gilmore attachment." J Prosthet Dent 16(6): 1090-1102.

Beresin, V. E. and F. J. Schiesser (1976). "The neutral zone in complete dentures." J Prosthet Dent 36(4): 356-367.

Bergendal, T. and B. Engquist (1998). "Implant-supported overdentures: a longitudinal prospective study." Int J Oral Maxillofac Implants 13(2): 253-262.

Bohanan, H. (1954). "A critical analysis of the mucostatic principle." J Prosthet Dent 4: 232-241.

Boucher, C. (1943). "Impressions for complete dentures." J Am Dent Assoc 30: 14-25.

Boucher, C. (1944). "Complete denture impressions based on anatomy of the mouth." J Am Dent Assoc 31: 124.

Boucher, C. (1951). "A critical analysis of the mid-century impression techniques for full dentures." J Prosthet Dent 1: 472-492.

Boucher, C. (1990). Boucher's prosthodontics treatment for edentulous patients. St Louis, The C.V Mosby Co. .

Boucher, C. and J. Hickey (1975). prosthodontic treatment for edentulous patients. Saint Louis, The CV Mosby Co.

Breeding, L. C., D. L. Dixon, et al. (1996). "The effect of simulated function on the retention of bar-clip retained removable prostheses." J Prosthet Dent 75(5): 570-573.

Burns, D. R., J. W. Unger, et al. (1995). "Prospective clinical evaluation of mandibular implant overdentures: Part I--Retention, stability, and tissue response." J Prosthet Dent 73(4): 354-363.

Burns, D. R., J. W. Unger, et al. (1995). "Prospective clinical evaluation of mandibular implant overdentures: Part II--Patient satisfaction and preference." J Prosthet Dent 73(4): 364-369.

Cavallaro, J. S., Jr. and D. P. Tarnow (2007). "Unsplinted implants retaining maxillary overdentures with partial palatal coverage: report of 5 consecutive cases." The International journal of oral & maxillofacial implants 22(5): 808-814.

Chung, K. H., C. Y. Chung, et al. (2004). "Retention characteristics of attachment systems for implant overdentures." J Prosthodont 13(4): 221-226.

Collett, H. A. (1970). "Final impressions for complete dentures." J Prosthet Dent 23(3): 250-264.

Crum, R. J. and G. E. Rooney, Jr. (1978). "Alveolar bone loss in overdentures: a 5-year study." J Prosthet Dent 40(6): 610-613.

Davis, D. M. (1990). "Role of implants in the treatment of edentulous patients." Int J Prosthodont 3(1): 42-50.

de Albuquerque Junior, R. F., J. P. Lund, et al. (2000). "Within-subject comparison of maxillary long-bar implant-retained prostheses with and without palatal coverage: patient-based outcomes." Clin Oral Implants Res 11(6): 555-565.

Devan, M. (1952). "Basic principles of impression making." J Prosthet Dent 2(1): 26-35.

el-Charkawi, H. G., N. A. Yehia, et al. (1995). "Load distribution in osseointegrated implant supporting extended and non extended dentures." Egypt Dent J 41(4): 1347-1356.

Epstein, D. D., P. L. Epstein, et al. (1999). "Comparison of the retentive properties of six prefabricated post overdenture attachment systems." J Prosthet Dent 82(5): 579-584.

Evtimovska, E., R. Masri, et al. (2009). "The change in retentive values of locator attachments and hader clips over time." Journal of prosthodontics : official journal of the American College of Prosthodontists 18(6): 479-483.

Fanuscu, M. I. and A. A. Caputo (2004). "Influence of attachment systems on load transfer of an implant-assisted maxillary overdenture." J Prosthodont 13(4): 214-220.

Federick, D. R. and A. A. Caputo (1996). "Effects of overdenture retention designs and implant orientations on load transfer characteristics." J Prosthet Dent 76(6): 624-632.

Fish, W. (1964). Principles of full denture prosthesis. Springfield, Charles C Thomas.

Frank, R. P. (1970). "Controlling pressures during complete denture impressions." Dent Clin North Am 14(3): 453-470.

Freeman, S. P. (1969). "Impressions for complete dentures." J Am Dent Assoc 79(5): 1173-1178.

Fry, K. (1923). "The retention of complete dentures." Br Dent J 44: 97.

Gamborena, J. I., L. R. Hazelton, et al. (1997). "Retention of ERA direct overdenture attachments before and after fatigue loading." Int J Prosthodont 10(2): 123-130.

Geertman, M. E., A. P. Slagter, et al. (1994). "Comminution of food with mandibular implant-retained overdentures." J Dent Res 73(12): 1858-1864.

Giddon DB, D. M., Pfaffman C, Manley RS (1954). "Relative abilities of natural and artificial dentition patients for judging the sweetness of solid foods." J Prosthet Dent 4: 263-268.

GPT-8 (2005). "The glossary of prosthodontic terms." J Prosthet Dent 94(1): 10-92.

Gulizio, M. P., J. R. Agar, et al. (2005). "Effect of implant angulation upon retention of overdenture attachments." J Prosthodont 14(1): 3-11.

Heartwell, C. and A. Rahn (1974). Syllabus of complete dentures. Philadelphia, New York, Lea and Febiger.

Henking, J. P. (1982). "Overdentures." J Dent 10(3): 217-225.

Howland, C. (1921). "The retention of artificial dentures." Dent Digest 27: 159.

Ichikawa, T., M. Horiuchi, et al. (1996). "In vitro study of mandibular implant-retained overdentures: the influence of stud attachments on load transfer to the implant and soft tissue." Int J Prosthodont 9(4): 394-399.

Jacobson, T. E. and A. J. Krol (1983). "A contemporary review of the factors involved in complete denture retention, stability, and support. Part I: retention." J Prosthet Dent 49(1): 5-15.

Jacobson, T. E. and A. J. Krol (1983). "A contemporary review of the factors involved in complete dentures. Part II: stability." J Prosthet Dent 49(2): 165-172.

Jacobson, T. E. and A. J. Krol (1983). "A contemporary review of the factors involved in complete dentures. Part III: support." J Prosthet Dent 49(3): 306-313.

Jemt, T., J. Chai, et al. (1996). "A 5-year prospective multicenter follow-up report on overdentures supported by osseointegrated implants." Int J Oral Maxillofac Implants 11(3): 291-298.

Jemt, T. and P. A. Stalblad (1986). "The effect of chewing movements on changing mandibular complete dentures to osseointegrated overdentures." J Prosthet Dent 55(3): 357-361.

Jivraj, S., W. Chee, et al. (2006). "Treatment planning of the edentulous maxilla." Br Dent J 201(5): 261-279; quiz 304.

Kenney, R. and M. W. Richards (1998). "Photoelastic stress patterns produced by implant-retained overdentures." J Prosthet Dent 80(5): 559-564.

Kiener, P., M. Oetterli, et al. (2001). "Effectiveness of maxillary overdentures supported by implants: maintenance and prosthetic complications." Int J Prosthodont 14(2): 133-140.

Koran, A., 3rd (1980). "Impression materials for recording the denture bearing mucosa." Dent Clin North Am 24(1): 97-111.

Kydd, W. L., C. H. Daly, et al. (1971). "The thickness measurement of masticatory mucosa in vivo." International dental journal 21(4): 430-441.

Lewis, S., A. Sharma, et al. (1992). "Treatment of edentulous maxillae with osseointegrated implants." J Prosthet Dent 68(3): 503-508.

Masri, R., C. F. Driscoll, et al. (2002). "Pressure generated on a simulated oral analog by impression materials in custom trays of different designs." J Prosthodont 11(3): 155-160.

Meijer, H. J., J. H. Kuiper, et al. (1992). "Stress distribution around dental implants: influence of superstructure, length of implants, and height of mandible." J Prosthet Dent 68(1): 96-102.

Meijer, H. J., F. J. Starmans, et al. (1993). "A comparison of three finite element models of an edentulous mandible provided with implants." J Oral Rehabil 20(2): 147-157.

Meijer, H. J., F. J. Starmans, et al. (1993). "A three-dimensional, finite-element analysis of bone around dental implants in an edentulous human mandible." Arch Oral Biol 38(6): 491-496.

Menicucci, G., P. Ceruti, et al. (2006). "A preliminary in vivo trial of load transfer in mandibular implant-retained overdentures anchored in 2 different ways: allowing and counteracting free rotation." Int J Prosthodont 19(6): 574-576.

Menicucci, G., M. Lorenzetti, et al. (1998). "Mandibular implant-retained overdenture: finite element analysis of two anchorage systems." Int J Oral Maxillofac Implants 13(3): 369-376.

Mensor, M. C., Jr. (1973). "Classification and selection of attachments." J Prosthet Dent 29(5): 494-497.

Mensor, M. C., Jr. (1978). "Attachment fixation of the overdenture: part II." J Prosthet Dent 39(1): 16-20.

Mericske-Stern, R. (1993). "Forces on implants supporting overdentures: a preliminary study of morphologic and cephalometric considerations." Int J Oral Maxillofac Implants 8(3): 254-263.

Mericske-Stern, R. (1998). "Three-dimensional force measurements with mandibular overdentures connected to implants by ball-shaped retentive anchors. A clinical study." Int J Oral Maxillofac Implants 13(1): 36-43.

Mericske-Stern, R. (1998). "Treatment outcomes with implant-supported overdentures: clinical considerations." J Prosthet Dent 79(1): 66-73.

Mericske-Stern, R., J. Hofmann, et al. (1993). "In vivo measurements of maximal occlusal force and minimal pressure threshold on overdentures supported by implants or natural roots: a comparative study, Part 1." Int J Oral Maxillofac Implants 8(6): 641-649.

Mericske-Stern, R., M. Piotti, et al. (1996). "3-D in vivo force measurements on mandibular implants supporting overdentures. A comparative study." Clin Oral Implants Res 7(4): 387-396.

Miller, P. A. (1958). "Complete dentures supported by natural teeth." J Prosthet Dent 8: 924-928.

Misch, C. E. (2005). Dental Implant Prosthetics. St. Louis, Elsevier Mosby.

Moses, C. (1953). "Physical considerations in impression making." J Prosthet Dent 3: 449-463.

Muller, H. P., N. Schaller, et al. (2000). "Thickness of masticatory mucosa." Journal of clinical periodontology 27(6): 431-436.

Naert, I., S. Gizani, et al. (1999). "A 5-year prospective randomized clinical trial on the influence of splinted and unsplinted oral implants retaining a mandibular overdenture: prosthetic aspects and patient satisfaction." J Oral Rehabil 26(3): 195-202.

Naert, I., M. Quirynen, et al. (1994). "A comparative prospective study of splinted and unsplinted Branemark implants in mandibular overdenture therapy: a preliminary report." J Prosthet Dent 71(5): 486-492.

Ochiai, K. T., B. H. Williams, et al. (2004). "Photoelastic analysis of the effect of palatal support on various implant-supported overdenture designs." J Prosthet Dent 91(5): 421-427.

Page, h. (1946). "Mucostatics, a principle not a 'technique"." Chicago, Published by the author: 22-23.

Page, h. (1947). "Mucostatics A practical comparison." Tic.

Page, H. (1949). "Mucostatics: A brief introduction." Tic.

Porter, J. A., Jr., V. C. Petropoulos, et al. (2002). "Comparison of load distribution for implant overdenture attachments." Int J Oral Maxillofac Implants 17(5): 651-662.

Rahn, A. and C. Heartwell (1992). textbook of complete dentures. Philadelphia, Lea & Febiger.

Rismanchian, M., F. Bajoghli, et al. (2009). "Effect of implants on maximum bite force in edentulous patients." J Oral Implantol 35(4): 196-200.

Rissin, L., J. E. House, et al. (1978). "Clinical comparison of masticatory performance and electromyographic activity of patients with complete dentures, overdentures, and natural teeth." J Prosthet Dent 39(5): 508-511.

Roberts, A. (1951). "principles of full denture impression making and their application in practice." J Prosthet Dent 1: 213-228.

Rodriguez, A. M., I. H. Orenstein, et al. (2000). "Survival of various implant-supported prosthesis designs following 36 months of clinical function." Ann Periodontol 5(1): 101-108.

Rutkunas, V., H. Mizutani, et al. (2005). "Evaluation of stable retentive properties of overdenture attachments." Stomatologija 7(4): 115-120.

Sadowsky, S. J. (2007). "Treatment considerations for maxillary implant overdentures: a systematic review." J Prosthet Dent 97(6): 340-348.

Sadowsky, S. J. and A. A. Caputo (2000). "Effect of anchorage systems and extension base contact on load transfer with mandibular implant-retained overdentures." J Prosthet Dent 84(3): 327-334.

Sadowsky, S. J. and A. A. Caputo (2004). "Stress transfer of four mandibular implant overdenture cantilever designs." J Prosthet Dent 92(4): 328-336.

Schacher, B., T. Burklin, et al. (2010). "Direct thickness measurements of the hard palate mucosa." Quintessence international 41(8): e149-156.

Schneider, A. L. and G. M. Kurtzman (2001). "Bar overdentures utilizing the Locator attachment." Gen Dent 49(2): 210-214.

Shafie, H. (2006). Clinical and Laboratory Manual of Implant Overdentures Balkwell Publishing LTD.

Shannon, I. L., J. M. Terry, et al. (1970). "Palatal coverage and parotid flow rate." J Prosthet Dent 24(6): 601-607.

Skinner, E. W. and P. Chung (1951). "The effect of surface contact in the retention of a denture." J Prosthet Dent 1(3): 229-235.

Sposetti, V. J., C. H. Gibbs, et al. (1986). "Bite force and muscle activity in overdenture wearers before and after attachment placement." J Prosthet Dent 55(2): 265-273.

Stanitz, J. (1948). "An analysis of the part played by the fluid film in denture retention." J Am Dent Assoc 37: 168-172.

Staubli, P. (1996). Attachments and implants. Reference manual. San Mateo, CA, Attachments International, INC.

Strain, J. (1952). "The influence of completed dentures upon taste perception." J Prosthet Dent 2: 60-67.

Studer, S. P., E. P. Allen, et al. (1997). "The thickness of masticatory mucosa in the human hard palate and tuberosity as potential donor sites for ridge augmentation procedures." Journal of periodontology 68(2): 145-151.

Sussman, B. (1960). "procedures in complete denture prosthesis." J Prosthet Dent 10: 1011.

Tallgren, A. (1966). "The reduction in face height of edentulous and partially edentulous subjects during long-term denture wear. A longitudinal roentgenographic cephalometric study." Acta Odontol Scand 24(2): 195-239.

Tallgren, A. (1972). "The continuing reduction of the residual alveolar ridges in complete denture wearers: a mixed-longitudinal study covering 25 years." J Prosthet Dent 27(2): 120-132.

Thomason, J. M. (2002). "The McGill Consensus Statement on Overdentures. Mandibular 2-implant overdentures as first choice standard of care for edentulous patients." Eur J Prosthodont Restor Dent 10(3): 95-96.

Tokuhisa, M., Y. Matsushita, et al. (2003). "In vitro study of a mandibular implant overdenture retained with ball, magnet, or bar attachments: comparison of load transfer and denture stability." Int J Prosthodont 16(2): 128-134.

van Kampen, F. M., A. van der Bilt, et al. (2002). "The influence of various attachment types in mandibular implant-retained overdentures on maximum bite force and EMG." J Dent Res 81(3): 170-173.

van Steenberghe, D. (1989). "A retrospective multicenter evaluation of the survival rate of osseointegrated fixtures supporting fixed partial prostheses in the treatment of partial edentulism." J Prosthet Dent 61(2): 217-223.

Walton, J. N., M. I. MacEntee, et al. (2002). "One-year prosthetic outcomes with implant overdentures: a randomized clinical trial." Int J Oral Maxillofac Implants 17(3): 391-398.

Wara-aswapati, N., W. Pitiphat, et al. (2001). "Thickness of palatal masticatory mucosa associated with age." J Periodontol 72(10): 1407-1412.

Wilson, G. (1920). A manual of dental prosthesis. Philadelphia
New York, Lea & Febiger.

Winkler, S. (1994). Essentials of complete denture prosthodontics. St. Louis, Ishiyaku EuroAmerica.

Yeh, C. K., D. A. Johnson, et al. (2000). "Association of salivary flow rates with maximal bite force." J Dent Res 79(8): 1560-1565.

Zarb, G. A. and A. Schmitt (1990). "The longitudinal clinical effectiveness of osseointegrated dental implants: the Toronto study. Part I: Surgical results." J Prosthet Dent 63(4): 451-457.

Zarb, G. A. and A. Schmitt (1990). "The longitudinal clinical effectiveness of osseointegrated dental implants: the Toronto Study. Part II: The prosthetic results." J Prosthet Dent 64(1): 53-61.

Zarb, G. A. and A. Schmitt (1990). "The longitudinal clinical effectiveness of osseointegrated dental implants: the Toronto study. Part III: Problems and complications encountered." J Prosthet Dent 64(2): 185-194.

Zitzmann, N. and C. Marinello (2001). " Decision-making and treatment planning in the edentulous mandible restored with fixed and removable implant prostheses." World Dent 1(2).