Comparison of Retention and Stability of Implant-Retained Overdentures Based Upon Implant Location, Number, and Distribution

Thesis

Presented in Partial Fulfillment of the Requirements for the Master of Science in the Graduate School of The Ohio State University

By

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2012

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Abstract

Statement of Problem: The location of dental implants and respective retentive attachments for implant-retained overdentures is selected based upon clinician preference, expert opinion, or empirical information. Limited information is available regarding implant position, distribution, and number and the effect upon the retention and stability of mandibular implant overdentures.

Purpose: The purpose of this investigation is to evaluate the effect of location, distribution, and number of implants upon in vitro retention and stability of a simulated implant-supported overdenture and to examine differences between several different attachment systems.

Methods and Materials: An experiment was undertaken utilizing a model simulating a mandibular edentulous ridge with 11 dental implants in positions on the model approximating the tooth position in the natural dentition. A cobalt-chromium cast framework with 3 loops, acrylic resin inside the housing, and chains attached to a universal testing machine was used to measure peak load (N) required to disconnect an attachment. Four different types of attachments were used in various positions on the model in sequence. Part I of the study evaluated the effect of implant location upon
retention and stability of a simulated 2 implant-retained overdenture. Part II of the study evaluated retention and stability of 1,2,3, or 4 implant-retained overdentures based upon implant number and distribution. For each group, 10 measurements were made of peak dislodging forces. Means were calculated and differences among the systems, directions, and groups were identified using a repeated measured analysis of variance at the p < 0.05 level. For differences observed between measurements, the Bonferroni post hoc method at the 5% level of significance was used to determine the location and magnitude of difference.

Results: For Part I, the 2-implant model, the interactions between attachment system, direction of force, and implant location were statistically significant (p < 0.001). Vertical retention and horizontal stability of a simulated overdenture prosthesis increased with distal implant location up to the 2nd premolar. Antero-posterior stability increased as implant location was placed distally. Attachment type affects retention and stability differently by location. Ball attachments reported the highest levels of retention and stability. For Part II, the 1, 2, 3, and 4 implant model, vertical retention of a simulated overdenture prosthesis increased with additional widely spaced implants. Horizontal stability of a simulated overdenture prosthesis increased with additional widely spaced implants except in the 2-implant model. Antero-posterior stability of a simulated overdenture prosthesis increased with additional widely spaced implants.
**Conclusions:** Within the limitations of this study, retention and stability of a 2-implant simulated overdenture prosthesis is significantly affected by implant location \((p < 0.001)\). Retention and stability of a simulated prosthesis is also significantly affected by implant number, distribution, and position \((p < 0.001)\).
Dedicated to Melissa who supported me through everything and my father who left us too early to see how far we have gone.
Acknowledgements

I wish to acknowledge my committee members, Dr. Robert Seghi, Dr. Edwin McGlumphy, and Dr. Binnaz Leblebicioglu, for their insight and assistance that have made this study possible. I wish to thank the Zimmer Institute for providing the test model. I also wish to thank Steve Ott for providing the implants used in the study. I wish to thank Mr. Steve Schiess and Zest Anchors for providing the Locator and Saturno attachments. I wish to thank Dr. McGlumphy for providing Ball attachments. I wish to thank Mr. James Ellison and Ms. Vicki Savino and Sterngold Dental for providing ERA attachments and the ERA-PickUp resin. I wish to extend a special thank you to Dr. William Johnston for his incredible and thoughtful statistical analysis.
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Chapter 1: Introduction
Tooth loss is a multifactorial and often a complex interaction of multiple comorbidities that, left unresolved, may progress to complete edentulism.\textsuperscript{1} Edentulism is defined as the state of being without natural teeth and represents a terminal process.\textsuperscript{2} While the rate of edentulism has been decreasing throughout the past three decades, the subsequent increase in the world population has resulted in an increasing growth of total edentulous persons\textsuperscript{3}. Between 1988 and 2002, the total percentage of edentulous individuals in the United States decreased from 10.5\% to 8\%.\textsuperscript{4,5} During this same time period the total population increased from 245 million to 288 million individuals, representing a net decrease of over 2.6 million individuals when comparing edentulism rates across the entire population.\textsuperscript{5} These figures, however, do not accurately represent the true total number of edentulous dental arches because a substantially higher older population increase is expected to occur. This older cohort tends to have significantly higher levels of edentulism and the actual true number of edentulous arches is expected to rise from 57 million in 2000 to 61 million in 2020.\textsuperscript{6} As a result of the anticipated increase in edentulism, the demand for treatment will increase.

The traditional treatment modality of edentulism has been the fabrication of removable, tissue-supported complete dentures.\textsuperscript{6} Three main factors are involved in optimal denture treatment: retention, support, and stability.\textsuperscript{7-9} While there are varied opinions regarding the importance of each of these three factors involved in treatment, it is critical to evaluate and properly estimate their contribution to optimal denture and
overdenture function, comfort, and patient acceptance. Retention of artificial tooth substitutes is related to the ability of a prosthesis to resist the forces of dislodgment along the path of insertion or placement of the prosthesis.\textsuperscript{2} Retention is often cited as being an important factor in denture treatment whereas stability is reported as being the most important factor.\textsuperscript{7} Stability is defined as the resistance to horizontal displacement of a prosthesis and without stability, the effect of retention and support are negated.\textsuperscript{2,8} Support is provided by the tissue surface of the mandibular edentulous ridge. In choosing between treatment approaches, patients often choose the treatment that increases stability even when cost is a major factor.\textsuperscript{10}

Historically, one of the greatest challenges facing the clinician is to provide a removable prosthesis with adequate retention and stability.\textsuperscript{11-13} Confirmation and amount of mandibular residual ridge is correlated with the retention and stability of the denture; both of these factors are implicated in patient satisfaction of a mandibular complete denture.\textsuperscript{7-8,14} Residual alveolar ridge resorption that occurs with tooth loss is a progressive condition that may result in substantial loss in denture bearing surfaces.\textsuperscript{15}

Overdentures have been advocated as a means to preserve the structures associated with mandibular denture support which may augment retention and stability.\textsuperscript{10} Authors have advocated several advantages of overdentures as compared to traditional dentures including: considerably enhanced stability, increased retention, sensory feedback, preservation of vertical dimension & prevention of overclosure, oro-facial
support, chewing efficiency, comfort, and increased support.\textsuperscript{16-19} Originally introduced in 1958\textsuperscript{20}, the overdenture has long been recognized as a method of maintaining alveolar ridge integrity and periodontal ligament mechanoreception, increasing denture stability, and, potentially, increasing retention. Early reports and techniques tended to direct prosthetic treatment to the availability of remaining teeth and the root forms that could support and retain a prosthesis. In the edentulous mandibular arch, the canines and premolars have been reported as the most resilient teeth and usually the last to be lost.\textsuperscript{21-22} Radicular bar, stud and magnetic attachments were developed to facilitate overdenture retention.\textsuperscript{21-23} Due to the potential benefit of incorporating attachments, clinicians began to develop overdenture treatment protocol and criteria. As a result, authors developed recommendations on abutment selection, distribution, and support criteria for overdentures.\textsuperscript{24}

While root overdentures are an effective method of increasing use of a removable prosthesis, individuals who are completely edentulous may benefit from dental implant therapy utilizing the overdenture concept. Early reports investigating the effectiveness of implant-retained overdentures were mostly positive including a majority of patients reporting that their prosthesis was better than it was without dental implants.\textsuperscript{25} Additionally, subjective reporting from the patients successfully treated in these early studies reported improved function including a perceived increase in bite force, chewing pattern, and chewing efficiency with little soft tissue adverse effects.\textsuperscript{26-27}
The implant-retained mandibular overdenture generally consists of three main components: the implant, the abutment containing one half of the attachment system, and the overdenture prosthesis, which houses the other half of the attachment system.\textsuperscript{22} The treatment of the edentulous mandible with the 2 implant implant-retained is a well-accepted treatment option with long-term successful outcomes of prostheses and implants.\textsuperscript{28} Evidence has supported the treatment philosophy of focusing on providing proper standard of care within the realms of simplicity versus overly complicated. In a randomized clinical trial, it was shown that there was no major difference between the simple approach and a more complicated one and that quality of the denture does not suffer when manufacturing techniques are simplified to save time and materials.\textsuperscript{29} The use of stud-style attachments is considered a simplified and cost-effective treatment as compared to bar and clip type implant overdentures. The prosthetic and attachment system factors involved with treatment planning successful mandibular implant overdentures have been the subject of extensive literature review.\textsuperscript{30-31} Included in this discussion is the anchorage design and space requirements, number of implants required, effect upon alveolar bone and anatomical factors, cost & maintenance, effects of antagonistic arch, stress distribution, and patient satisfaction. Missing from these discussions, however, is an analysis of implant location and distribution upon the aforementioned prosthetic factors.
Retention of commercially available stud attachment systems has been the subject of many in vitro studies.\textsuperscript{32-40} While most of these studies assumed a 2-implant model approximating the location of the mandibular canines, few studies have evaluated in vitro retention of prostheses outside of the areas of the mandibular canines. Retention and stability has been measured comparing number implants for implant-retained and supported overdentures\textsuperscript{41-45}, however, the studies do not describe the prosthetic factors in relation to implant position and distribution.

While many of these studies focus their attention on the retention, release, and stability between types and forms of attachments, few have investigated overdenture properties as a function of attachment location, distribution, and number of implants. The impact of distribution and number of implants and attachment systems upon retention and stability of overdentures has been alluded to in several studies.\textsuperscript{22,45-51} Many of these authors justified the use of well distributed teeth and implants based upon empirical information, however, few studies have accurately evaluated the effect of implant distribution and number upon the retention and stability of overdenture prostheses. To the knowledge of the authors of the current study, only two studies have attempted to evaluate the aforementioned factors. Wahab and Sadig designed several models for testing magnetic retention of overdentures including one two-implant model, two four implant models, and one six implant model.\textsuperscript{52} The authors were able to determine that retention and stability of overdentures could be improved by altering implant location and
distribution. Fatalla et al investigated distribution of implants according to two main designs: triangular versus quadrangular support. The authors determined that after cyclic loading and wear analysis that wide, even distribution of attachments provided the highest level of retention and stability.

In consideration of the currently available studies, limited information exists regarding implant position, distribution, and number and the effect upon the retention and stability of mandibular implant overdentures. The purpose of this investigation was to provide an in vitro evaluation of the effect of implant location, distribution, and number upon the magnitude of force required to dislodge implant overdenture prostheses.
Thesis Design

The thesis comprises two parts: part I focuses on a 2-implant retained overdenture model and part II focuses on a 1, 2, 3, and 4-implant retained overdenture model.

Part I: Comparison of retention and stability of a 2 implant-retained overdentures based upon implant location

Part II: Comparison of retention and stability of implant-retained overdentures based upon implant number and distribution
Aims of Thesis

The aims of this investigation are the following:

1. Evaluate the effect of anatomical location of retentive element of an implant upon in vitro retention and stability of a simulated implant-supported overdenture.
2. Evaluate the effect of distribution of implant retentive elements upon in vitro retention and stability of a simulated implant-supported overdenture.
3. Evaluate the effect of number of implant retentive elements upon in vitro retention and stability of a simulated implant-supported overdenture.
4. Examine differences between attachment systems in regards to location, distribution, and number.

The hypothesis tested was that the implant location, distribution, and number affect in vitro retention and stability of a simulated implant overdenture.

The null hypothesis was that implant location, distribution, and number does not affect in vitro retention and stability of a simulated implant overdenture.
Chapter 2: Material & Methods
An experiment was undertaken utilizing a model simulating a mandibular edentulous ridge with 11 dental implants in positions on the model approximating the tooth positions in the natural dentition (Figure 1). A cobalt-chromium cast framework with 3 loops, acrylic resin inside the housing, and chains attached to a universal testing machine was used to measure peak load (N) required to disconnect an attachment (Figure 2). 4 different types of attachments were used in 5 positions on the model in sequence of 2 implants at a time.

Model Preparation

A model simulating a mandibular edentulous ridge (Zimmer Institute, Carlsbad CA) was selected and 11 Tapered Screw Vent implants (Zimmer Dental, Carlsbad CA) were placed in the following positions based upon tooth arrangement #18, 20, 21, 22, 23, 24/25, 26, 27, 28, 29, 31. Implants were placed with a surveyor (Ney Surveyor, Dentsply, York, PA) and a drill press (Paraskop M, BEGO, Lincoln, RI) to ensure parallelism between components. Implant-level transfer impressions posts were attached to the implants on the model and a vinyl polysiloxane (PVS) impression (Aquasil, Dentsply, York, PA) was made of the implants and model. 11 additional implants were attached to the direct transfers and a gingival tissue analog (Gingitech, Ivoclar Vivadent, Amherst, NY) was injected to simulate 3mm of soft tissue covering the surface of the model.
Autopolymerizing polymethyl methacrylate (PMMA) acrylic resin (Dentsply, York, PA) was added incrementally to fabricate a test model with no undercuts present. (Fig. 1)

Fig. 1. Acrylic resin test model and 3mm gingival analog with 11 Zimmer Dental implants placed approximating teeth # 18, 20, 21, 22, 23, 24/25, 26, 27, 28, 29, 31.
A cast cobalt-chromium framework (NobilStar-Nobilium, Albany, NY) was fabricated to act as a denture base throughout treatment. Three withdrawal loops were incorporated into the framework one approximating the incisor region and the other two approximating the first molar regions. (Fig. 2)

Fig. 2. Cobalt-chromium cast framework with three loops approximating incisor and molar regions.
Autopolymerizing polymethyl methacrylate (PMMA) acrylic resin (Dentsply, York, PA) was incorporated in the intaglio and facial/lingual surfaces of the framework to allow for attachment of the matrix portions. The metal framework remained constant throughout testing. Four commercially available attachment designs were evaluated: ERA orange (Sterngold, Attleboro, MA), O-Ring Saturno standard (Zest Anchors, Escondido, CA), Locator pink (Zest Anchors, Escondido, CA), Ball clear (Zimmer Dental, Carlsbad, CA). (Fig. 3)
The occlusal plane of the test model was set even with the horizontal plane of a metal plate (150mm x 75mm x 4mm) and 3 #8-32 bolts were placed to affix the model to the metal plate. The incorporation of the plate allows precise reproduction of the position of the model clamping to the testing apparatus for the different attachment systems. A universal testing machine (Model 5500R, Instron, Norwood, MA) was applied to test forces required to dislodge the prosthesis in various directions as previously described. Three 6.2cm metal chains were attached to an 8.0mm washer with three #8-32 x 41mm eye bolts in a triangular orientation with #8-32 machine screw nuts. The washer was attached in the center with 6.35mm bolt and nut to a ball/socket pivoting joint assembly incorporated into the universal testing machine. (Fig. 4) The use of the eye bolts and pivoting joint allowed for precise adjustment of the chains and to ensure that all chains were pulling evenly throughout the experiment.
Fig. 4. Experimental test model attached to universal testing machine base with clamps. The washer, eye bolts, and pivoting joint assembly allowed for adjustment of the slack in the chains and for correction of pivoting throughout the experiment.
The testing machine instrumentation was calibrated and balanced using the testing machine’s computer algorithm to account for the weight of the simulated prosthesis and chains. Three chains were attached to the prosthesis and a 3-point vertical pull was used to determine retention against a vertically directed dislodging force parallel to the path of insertion. A 2-point oblique/posterior pull was used to determine stability to determine resistance against para-axial, oblique dislodging forces. Two chains were attached: one in incisor region and alternating chains either on the right or left side molar region. To test posterior dislodging forces, the incisor chain was removed and the remaining two chains were attached in the molar regions.

The chains were adjusted to reduce slack and force was applied until separation of the prosthesis occurred. The dislodging force applied resulted in a peak load measurement (Newtons, N) that was graphically recorded on a computer with analytical software (Partner, Instron, Norwood, MA). The horizontal load frame and load cell was set at a constant crosshead speed, 50.8mm/minute, previously described as the approximate speed of movement of a denture from the ridge during mastication.\textsuperscript{33,39,45}

For each group, 10 measurements were made of peak dislodging forces. Means were calculated and differences among the systems, directions, and groups were identified using a repeated measured analysis of variance at the $\alpha < 0.05$ level. Power analysis was performed and the smallest differences between means were determined. The oblique dislodging forces between alternating right/left sides were averaged to report
a single oblique dislodging force (N) mean value. For differences observed between
measurements, the Bonferroni post hoc method at the 5% level of significance was used
to determine the location and magnitude of significant differences (SAS ver. 9.2, Cary,
NC).
**Testing Parameters - Part I**

2 patrix portions of the attachment system were placed into areas designed as group numbers that approximate natural tooth positions: group 1 (#23,26), group 2 (#22,27), group 3 (#21,28), group 4 (#20,29), group 5 (#18,31). (Fig 5) Matrix housing portions of the attachment system were attached to the prosthesis following manufacturer guidelines with a bis-acryl material (ERA PickUp, Sterngold, Attleboro, MA).

![Fig. 5. Acrylic resin test model with dental implants separated into the following 5 designated groups (implant location): Group 1 (23/26), Group 2 (22,27), Group 3 (21,28), Group 4 (20,29), Group 5 (18,31).](image-url)
Testing Parameters - Part II

Patrix portions of the attachment system were placed into areas designed as group numbers that approximate natural tooth positions: Group 1 (1 implant - #24), Group 2 (2 implants - #22,27), Group 3 (2 implants - #20,29), Group 4 (3 implants - #22,24,27), Group 5 (3 implants - #20,24,29), and Group 6 (4 implants - #20,22,27,29). (Fig 6) Matrix housing portions of the attachment system were attached to the prosthesis following manufacturer guidelines with a bis-acryl material (ERA PickUp, Sterngold, Attleboro, MA).
Fig. 6. Acrylic resin test models with dental implants & attachments separated into the following 5 designated groups (implant location): Group 1 (1 implant - #24), Group 2 (2 implants - #22,27), Group 3 (2 implants - #20,29), Group 4 (3 implants - #22,24,27), Group 5 (3 implants - #20,24,29), and Group 6 (4 implants - #20,22,27,29)
Chapter 3: Results
Results - Part I

Results are presented in Figures 7 to 9. Peak load to dislodgement values for all groups ranged from 4.84 N to 37.17 N. Statistically significant differences were found between systems, directions, and groups (p < 0.05).

In the vertically directed test, peak load means ranged from 7.43 N to 37.17 N. (Fig. 7) Samples tested in group 1 reported the lowest force to dislodgement and samples in group 4 reported the highest force to dislodgement (Group 4 > Group 3 = Group 2 > Group 5 > Group 1). The means between groups was statistically significant (p < 0.001) for all groups except between groups 2 and 3 (p > 0.30). Statistically significant differences were found between systems (p < 0.001); Ball attachments had the highest mean retentive value and ERA orange had the lowest mean retentive value (Ball clear > Locator pink > O-Ring standard > ERA orange).

When comparing attachments, ERA and O-Ring attachments show similar behavior with implant location; both systems show increases in retentive values from group 1 to 2 (ERA: 7.43 N to 9.31 N, O-Ring: 9.96 N to 13.04 N) and from group 2 to 3 (ERA: 9.31 N to 11.56 N, O-Ring: 13.04 N to 15.17 N). This increase was statistically significant (p < 0.001), however, the retention differences between group 3 and 4 (p > 0.50) and group 2 and 5 locations (p > 0.70) were not statistically significant. Locator and ball attachments show large significant increases in retention from group 1 to 2 (p <
and subsequently show a decrease from group 2 to 3. The decrease from group 2 to 3 was significant for the Locator \((p < 0.001)\) but not for the Ball attachment \((p > 0.06)\). Both Locator and ball attachments had a significant increase in retentive values from group 3 to 4 \((p < 0.001)\) followed by significant decrease at group 5 \((p < 0.001)\).
Fig. 7. Mean values of vertical dislodgment force (N) of samples and error bars signifying 95% confidence intervals based upon observed within-group standard deviation. Means linked by horizontal bars were not found to be statistically significantly different (p > 0.05).
In the obliquely directed test, peak load means ranged from 4.84 N to 20.23 N. (Fig. 8) Samples tested in group 1 reported the lowest force to dislodgement and samples in group 3 reported the highest force to dislodgement (Group 3 > Group 2 > Group 4 > Group 5 = Group 1). The means between groups was statistically significant (p < 0.001) for all groups except between groups 1 and 5 (p > 0.13). Ball attachments had the highest mean retentive value and ERA had the lowest mean retentive value (Ball clear > Locator pink > O-Ring standard > ERA orange). Statistically significant differences between attachment systems at all groups (p < 0.001) except the following comparisons: Ball group 3 vs Locator group 3 (p > 0.05), ERA group 4 vs O-Ring group 4 (p > 0.20), ERA group 5 vs O-Ring group 5 (p > 0.60).

The ERA attachment shows the lowest dislodging force values at group 2 and highest at group 4. There was no statistical difference between groups 1 and 2 (p > 0.60) or groups 3 and 4 (p > 0.90). The O-Ring attachment shows statistically the highest oblique values at group 2 (p < 0.001) and the lowest at group 5 (p < 0.001). Group 1 showed a very large spread between measurements and the attachment values were not statistically different between group 4 and 5 (p > 0.60). The Locator attachment statistically hast the highest oblique values at group 3 (p < 0.001) and the lowest at group 1 (p < 0.001). Contrary to other systems, Locator had statistically lower values for group 4 than group 5 (p < 0.001). The Ball attachment had the highest oblique values at group
2, however, this value was not statistically different than group 1, 3, or 4 (p > 0.05). Group 5 had a statistically lower value than groups 2, 3, and 4 (p > 0.05).

Fig. 8. Mean values of oblique dislodgment force (N) of samples and error bars signifying 95% confidence intervals based upon observed within-group standard deviation. Means linked by horizontal bars were not found to be statistically significantly different (p > 0.05).
In the antero-posteriorly directed test, peak load means ranged from 5.92 N to 31.28 N. (Fig. 9) Samples tested in group 1 reported the lowest force to dislodgement and samples in group 5 reported the highest force to dislodgement (Group 5 > Group 4 > Group 3 > Group 2 > Group 1). The means between groups were statistically significant (p < 0.001). Statistically significant differences were found between systems (p < 0.001); Ball attachments had the highest mean retentive value and ERA had the lowest mean retentive value (Ball clear > Locator pink > O-Ring standard > ERA orange).

All attachment systems statistically showed the highest antero-posterior values at group 5 and the lowest at group 1 (p < 0.001). The ERA attachment shows the lowest values at group 1 and highest at group 5. There was no statistical difference between groups 1 and 2 (p > 0.09), groups 3 and 4 (p > 0.05), or groups 4 and 5 (p > 0.70). The O-Ring attachment showed the lowest values at group 2 and highest at group 5. Groups 4 and 5 had statistically higher values than groups 1, 2, and 3 (p < 0.001) but there was no statistical difference between groups 1 and 2 (p > 0.10). The Locator attachment statistically had the highest values at group 5 and the lowest at group 1 (p < 0.001). There was no statistical difference between groups 2, 3, and 4 (p > 0.20). The Ball attachment showed the highest values at group 5 and lowest at group 1. Groups 4 and 5 and groups 2 and 3 were not statistically different (p > 0.05) but groups 4 and 5 were statistically greater than groups 1, 2, and 3 (p < 0.001).
Fig. 9. Mean values of antero-posterior dislodgment force (N) of samples and error bars signifying 95% confidence intervals based upon observed within-group standard deviation. Means linked by horizontal bars were not found to be statistically significantly different ($p > 0.05$).
Results - Part II

Results are presented in Figures 10 to 12. Peak load to dislodgement values for all groups ranged from 2.70 N to 71.20 N. Statistically significant differences were found between systems, directions, and groups (p < 0.05).

In the vertically directed test, peak load means ranged from 3.98 N to 71.20 N. (Fig. 10) Samples tested in group 1 reported the lowest force to dislodgement and samples in group 6 reported the highest force to dislodgement (Group 6 > Group 5 > Group 4 > Group 3 > Group 2 > Group 1). The means between groups was statistically significant for all groups (p < 0.001). Statistically significant differences were found between systems (p < 0.001); Ball attachments had the highest mean retentive value and ERA had the lowest mean retentive value (Ball clear > Locator pink > O-ring standard > ERA orange). Statistically significant differences between attachment systems at all groups except the following comparisons: ERA group 1 vs. O-Ring group 1 (p > 0.10), ERA group 6 vs. O-Ring group 6 (p > 0.10).

When comparing attachments, ERA and O-Ring attachments show dramatic increases in retentive values from group 1 to 2 (ERA: 3.98 N to 9.31 N, O-Ring: 5.55 N to 13.04 N) and from group 5 to 6 (ERA: 12.00 N to 23.23 N, O-Ring: 13.72 N to 21.62 N). This increase was statistically significant (p < 0.001); however, the differences between group 3 and 5 for ERA and groups 2 and 5 for O-Ring were not statistically
significant (p > 0.50). For ERA and O-Ring attachments, a small but significant decrease in retention occurred between groups 3 and 4 (p < 0.50). Locator and Ball attachments show large significant increases in retention from group 1 to 5 (p < 0.001), except between groups 2 and 3 for Locator (p > 0.10). The results show large differences between retentive values between group 1 and 6; a 52.64 N increase is found for the Locator system and 53.15 N increase is found for the Ball system.
Fig. 10. Mean values of vertical dislodgment force (N) of samples and error bars signifying 95% confidence intervals based upon observed within-group standard deviation. Means linked by horizontal bars were not found to be statistically significantly different ($p > 0.05$).
In the obliquely directed test, peak load means ranged from 3.32 N to 44.60 N. (Fig. 11) Samples tested in group 1 reported the lowest force to dislodgement and samples in group 6 reported the highest force to dislodgement (Group 6 > Group 5 > Group 4 > Group 2 > Group 3 > Group 1). The means between groups was statistically significant for all groups (p < 0.001). Ball attachments had the highest mean retentive value and ERA had the lowest mean retentive value (Ball clear > Locator pink > O-ring standard > ERA orange). Statistically significant differences between attachment systems at all groups except the following comparisons: Ball group 4 vs Locator group 4 (p > 0.40).

The ERA attachment shows the lowest oblique dislodging force values at group 1 and highest at group 6. There was no statistical difference between groups 3 and 4 (p > 0.10). The O-Ring attachment shows statistically the highest oblique values at group 6 and the lowest at group 1 (p < 0.001). The O-Ring showed no statistical difference between groups 1 and 3 (p > 0.30) and 2 and 4 (p > 0.40). The Locator attachments statistically hast the highest oblique values at group 6 and the lowest at group 1 (p < 0.001). Similar to the O-Ring attachments, the Locator attachments had statistically lower values for group 3 than group 2 (p < 0.001). The Ball attachment had the highest oblique values at group 6 and the lowest at group 1. Group 2 was not statistically different than groups 3 or 4 (p > 0.70).
Fig. 11. Mean values of oblique dislodgment force (N) of samples and error bars signifying 95% confidence intervals based upon observed within-group standard deviation. Means linked by horizontal bars were not found to be statistically significantly different (p > 0.05).
In the antero-posteriorly directed test, peak load means ranged from 2.70 N to 35.39 N. (Fig. 12) Samples tested in group 1 reported the lowest force to dislodgement and samples in group 6 reported the highest force to dislodgement (Group 6 > Group 5 > Group 3 > Group 2 > Group 4 > Group 1). The means between groups was statistically significant (p < 0.001). Statistically significant differences were found between systems (p < 0.001); Ball attachments had the highest mean retentive value and ERA had the lowest mean retentive value (Ball clear > Locator pink > O-ring standard > ERA orange). Statistically significant differences between attachment systems at all groups except the following comparisons: O-Ring group 1 vs. Locator group 1 (p > 0.70).

All attachment systems statistically showed the highest antero-posterior values at group 5 and the lowest at group 1 (p < 0.001). The ERA attachment shows the lowest values at group 1 and highest at groups 3 and 5. There was no statistical difference between groups 2, 4 and 5 or groups 3 and 6 (p > 0.05). A significant drop in value occurred between groups 3 and 4, 5 (p < 0.001). The O-Ring attachment showed the lowest values at group 1 and highest at group 6. The O-Ring system differs from the other attachments in that a sudden drop in values between groups 4 and 5. The Locator attachment statistically had the highest values at group 6 and the lowest at group 1 (p < 0.001). There was no statistical difference between groups 2 and 3 (p > 0.20). The Ball attachment showed the highest values at group 6 and lowest at group 1. Groups 3 and 5
were not statistically different ($p > 0.90$). Interestingly, ERA, Locator, and Ball systems all had sudden drops in value between groups 3 and 4, however, O-Ring did not.

![Graph]

**Fig. 12.** Mean values of antero-posterior dislodgment force (N) of samples and error bars signifying 95% confidence intervals based upon observed within-group standard deviation. Means linked by horizontal bars were not found to be statistically significantly different ($p > 0.05$).
Chapter 4: Discussion
It is evident that many treatment concepts involving mandibular overdentures are based on empirical experiences of individuals.\textsuperscript{16-24} Clinicians often base their selection of implant location and attachment system empirically on expected retentive qualities. Evaluating these factors the results allow the clinician to formulate a comparison of implant location to retention and stability of an implant-retained overdenture prosthesis.

Retention is a major concern to patients and one of the greatest challenges facing clinicians is providing prosthetic treatment that provides retention patients desire.\textsuperscript{11-13} While retention and its effect upon overdenture prosthetic factors are related, few studies have established a consensus regarding what is considered sufficient retention. An in vitro study evaluated several different types of attachments and reported that retention strengths between 5 to 8 N are sufficient for implant-retained overdentures during long-term function.\textsuperscript{54} A prospective cross-over clinical study evaluated patient satisfaction and the correlation to force values and determined that approximately 10 N of retention was effective.\textsuperscript{55} This study was an effective measure of clinical factors related to prosthetic success and acceptance by the patients at several time points throughout treatment and patients preferred the attachment that provided greater retention. Based upon these studies, it can be established that an effective retentive force may be between 8 to 10 N.

Mandibular overdentures, when in place in the oral environment, move in complex ways. Movement of overdentures typically occurs in six directions: occlusal, gingival, mesial, distal, facial, and lingual. While true uni-directional dislodging forces
rarely occur in clinical scenarios, directional pull-testing is an effective way of measuring retention and stability of a prosthesis during in vitro laboratory evaluation.\textsuperscript{33-39}
Discussion - Part I

The present in vitro study investigated the effect of implant position on the retention and stability of a simulated prosthesis. To the knowledge of the authors of this publication, no studies have evaluated the effect of varying in vitro implant location upon dislodging forces of a simulated 2-implant overdenture prosthesis. The results of this study indicate that implant location affects in vitro retention and stability of an implant overdenture.

The current in vitro study reveals that vertical retention increases with distal implant location up to the 2nd premolar. In the vertical pull tests, the incisor region reported the lowest mean retentive values and steadily increased as implant position was moved distally. The highest values were reported in the 2nd premolar region and the values dropped when implants moved into the molar location. Regarding vertically directed forces, one would believe that retentive values would not change when implant location was modified. In the testing procedures, it was noted that during 3-point chain pull tests, some antero-posterior movement occurred. While this may have affected the reported force values, the method employed better simulates the movement of overdentures in clinical situations rather than utilizing a rigid design. The type of attachment affects the effect of vertically applied forces. ERA and O-Ring attachments showed similar trends as compared to each other. In these attachment types, the highest
level of force was required to dislodge implants located at the 1st and 2nd premolar locations and the lowest at the incisor location. In the Locator and Ball attachment systems, highest values were located at the 2nd premolar location and a significant drop in retention occurred when moving implants from the canine to 1st premolar location (p < 0.001) followed by a significant rise in retention to the 2nd premolar location (p < 0.001).

Horizontal displacement forces increase with distal implant location up to the 1st premolar. In the oblique pull tests, the results varied tremendously depending on the type of attachment utilized and the standard deviation between measurements was high. The ERA and Ball attachments had little variation between incisor and molar positions and while some results are statistically significant between groups (p < 0.001), the differences between them are very small. The O-Ring attachment saw a substantial decrease in dislodging forces in the 2nd premolar and molar implant positions indicating that incisor positioning of O-Ring attachments is more beneficial for horizontal stability than 2nd premolar or molar implant positions. Horizontal stability of locator attachments were affected by implant positioning and 1st premolar sites had the highest values. The results illustrate that with ERA and Ball attachments, implant has a minor effect on horizontal stability where for O-Ring and Locator attachments, horizontal stability is significantly affected by implant position (p < 0.001).

Dislodging forces that act upon overdentures are related to patient satisfaction of the prosthetic treatment. The stability of an overdenture prosthesis in an antero-
posterior direction leads to increased satisfaction in incising hard foods such as carrots and apples.\textsuperscript{55-56} In the present study, antero-posterior chain pulls were evaluated as an indirect method of determining the effect of implant location upon posterior dislodging forces. In all attachments systems tested, a general trend was determined that an increased resistance to dislodgment occurred as implant location was moved distally. This result was statistically significant for all groups (p < 0.001); however, variation was noted when analyzing attachment systems separately. ERA and O-Ring attachments showed moderate changes between incisor and canine locations but the value was not significant (p > 0.09). The Locator and Ball attachment systems showed that between canine and 1\textsuperscript{st} premolar regions, similar antero-posterior resistance values can be expected. Interestingly, all systems except the Locator group showed no significant increase in resistance in moving implant location from 2\textsuperscript{nd} premolar to molar regions (p > 0.05). Resistance values for all systems except for O-Ring were not significantly different between canine and 1\textsuperscript{st} premolar regions (p > 0.05).

The variation between attachment systems is of great interest when formulating conclusions regarding the effect of implant position upon retention and stability. The present study shows that attachment type affects retention and stability different by location. For example, in the vertical retention test, ERA and O-Ring attachments showed comparable behavior when moving implant location but were dissimilar to that of Locator and Ball attachments. Furthermore, in the antero-posterior dislodgement test,
ERA, O-Ring, and Ball attachments showed comparable behavior but were dissimilar to Locator attachments. The results of this study illustrate that attachment systems respond in different ways depending on their location in the edentulous arch. Therefore, if one uses 8 to 10 N of force as appropriate for retention of a prosthesis, an ERA attachment would not provide sufficient vertical retention in the incisor region but would in the canine and premolar areas. Furthermore, when considering posterior dislodging forces, ERA and O-Ring attachments would provide sufficient retention in the 1st and 2nd premolar location but not the incisor or canine locations. When evaluating the force values reported in this study, the interaction between attachment systems and implant location is statistically significant (p < 0.001).

In the present study, dislodging forces generally increased as implants were spaced further apart on the test model. Results of this study were similar to that found in previous studies in regards to inter-implant distance.57-58. Furthermore, the authors of these studies found that the effect of inter-implant spacing was especially evident with Ball type attachments as compared to other attachments. The magnitude of force values between Ball groups 1 through 5 in antero-posterior and vertically directed forces were the highest of all attachment systems. The results of this study indicate that inter-implant spacing had a significant effect on all the attachment systems tested (p < 0.001), with generally higher retention with greater inter-implant spacing.
Treatment evaluation of patients who present with edentulous mandibles involves teamwork between surgical and prosthetic approaches. Patients may be presented with several different options for implant prosthetic reconstruction that include: fixed metal-ceramic restorations, fixed complete denture restorations (hybrid), implant-supported removable overdentures, and implant-retained removable overdentures.\textsuperscript{59} As the population ages and economic factors affect treatment decisions, some patients elect to have 2 implants placed and an overdenture fabricated as a provisional prosthesis. This group of patients may wish to have treatment performed that would allow them add additional implants to convert their overdenture to a fixed prosthesis at some time point in the future. Surgical treatment has been well established for implant placement in the parasympphyseal region of the edentulous mandible for fixed and removable restorations.\textsuperscript{60-62}

Following the established 5-implant hybrid technique, figure 13 shows 5 possible locations for implant placement. Implants #1,5 are placed first based upon location and a recognized 3-5-mm safety zone anterior to the mental foramen.\textsuperscript{63-64} After locating the mandibular parasympheal midline, implant #3 is placed slightly to the right or left of the suture line. Marking the midline between #1/3 and #3/5, the surgeon places implants #2/4 last. Based upon historical overdenture therapy, restorative clinicians typically request the surgeons to place implants at the mandibular canine locations or #2/4 sites. When properly placed, implants at the #2/4 location for the purposes of provisional overdenture
therapy are effective and may be converted to a fixed restoration with the placement of additional implants. When improperly placed, however, conversion to a fixed restoration may be complicated. If the implants are placed too far mesially or distally in relation to proposed additional implant sites, encroachment of implants may occur which may lead to complications. From the results of this study, one can conclude that retention and stability of an implant-retained overdenture may be similar between implants at the mandibular canine location (#2/4) as compared to implants at the mandibular 1st premolar location (#1/5).

Fig. 13. Possible implant locations in the mandibular parasymphysyal region for 5-implant fixed complete denture (hybrid) protocol.
Caution must be emphasized, however, that these findings do not take into consideration the clinical reality of management of edentulous patients. The results of this study indicate that 2-implants may produce effective in vitro retention and stability of an overdenture prosthesis. The testing performed is limited with specific conditions and methods and does not completely replicate clinical situations as the implant overdenture clinical reality is much more complex than a laboratory setting can replicate. Furthermore, the findings of this study also do not account for attachment wear, resiliency, and tissue effects. While this in vitro based analysis shows a statistical difference between groups, long-term comparative prospective controlled studies are needed to reach agreement on an accepted treatment concept. Factors such as the type and location of implants placed, quality and quantity of bone, and type of superstructure should be part of these studies.

In evaluating implant location for implant-retained overdentures, it is important to consider the biomechanics of how the prosthesis functions. Levers are classified according to the relative location of the fulcrum and input and output forces. A class I lever contains a fulcrum between two forces, a class II lever contains resistance in the middle between the force and fulcrum, and a class III lever contains the effort between resistance and fulcrum. Previously considered in relation to removable partial denture design, Avant described the effect of indirect retainers upon the mechanical advantage of a distal extension base. The indirect retainer acts as the fulcrum, the direct retainer
assembly acts as the resistance, and the power is the force that lifts the denture base away from the ridge. Mechanical advantage was described as the measurement of the force required to overcome the resistance of the direct retainer. Avant described methods of lowering the mechanical advantage of the lever in order to keep the denture base from lifting away from the ridge. One method described was to shorten the power arm at the power end of the lever and the second was to lengthen the resistance arm at either one of the ends. The second method was applicable for use in removable partial denture design, which was the addition of an indirect retainer far from the effort source. Determination of mechanical advantage is performed by measuring the ratio of the power arm to the resistance arm (Fig. 14).

\[
\text{Mechanical Advantage} = \frac{\text{Power Arm}}{\text{Resistance Arm}}
\]

Fig. 14. Mechanical advantage is a function of the ratio of the length of the power arm to resistance arm.
When considering antero-posterior movement such as a dislodging force would provide, an implant overdenture may function as a class I, II or III lever. (Fig. 15)

![Fig. 15. Components of a Class I, II and III lever system with the implant and attachment serving as the resistance / fulcrum point.](image)

Assuming the example of an implant-retained overdenture prosthesis that is intimately fitting the soft tissue support, the fulcrum is the anterior alveolar ridge, the resistance is the attachment system, and the power is the posterior dislodging force lifting the denture base away from the ridge. Analyzing an example where implant location is
anterior, such as in the incisor region, figure 16 (A) illustrates a class I lever system. The fulcrum and resistance point would be coincident, thus making for a short resistance arm. Moving implant location distally, such as in the 1st premolar location, as shown in figure 16 (B), the resistance arm is substantially lengthened compared to that shown in figure 16 (A). This change would also modify the lever system to a class II.

Fig. 16. Components of a Class I, II lever system with the anterior residual alveolar ridge as the fulcrum point, implant and attachment serving as the resistance, and power is the posterior dislodging force.
The power required to exact a similar dislodging force would be much higher in example (B) due to the reduction in mechanical advantage by lengthening the resistance arm. This mechanical illustration may help explain the results of this study. As seen in the analysis of the antero-posterior dislodging force test, significantly higher forces were required to dislodge the prosthesis when implants were located distally on the test model. When comparing all the attachment systems as a function of groups, moving implants from group 1 to 4 reduced the mechanical advantage. Interestingly, when evaluating group 5, it is likely that the lever was functioning as a class III during these tests, since the power was located between the fulcrum and resistance. This concept may help explain the reason that why the ERA, O-Ring, and Ball attachment systems did not see a significant increase in resistance when moving from group 4 to 5.

Utilizing the formula illustrated in figure 14 with the measurements listed in figure 17, the following mechanical advantage ratios are determined: Group 1 – 3.55 > Group 2 – 2.50 > Group 3 – 1.66 > Group 4 – 1.13 > Group 5 - .67. The effect of this decrease is evident can be compared to the results of antero-posterior dislodging forces found in this study. Group 5 reported the highest values of dislodging forces where group 1 reported the lowest values, indicating that the lower mechanical advantage, the more force is required to dislodge the prosthesis away from the alveolar ridge. This finding is also supported by Avant’s evaluation of the effect of indirect retention upon a removable partial denture base.66
Fig. 17. Simulated overdenture test prosthesis super-imposed over model with implant positions, fulcrum and power locations illustrated. RA = Resistance Arm, PA = Power Arm.

It seems evident that many treatment concepts involving mandibular overdentures are based on empirical experiences of individuals. Clinicians often base their selection of implant location and attachment system empirically on expected retentive qualities. Scientifically evaluating these factors allow the clinician to formulate a comparison of implant location to retention and stability of an implant-retained overdenture prosthesis. The current in-vitro results support a proposed mechanical
advantage theory of implant-retained overdentures where placement of implants distally allows a reduction in the mechanical advantage. Placement of implants mesially, such as in the incisor region, may result in less resistance to dislodgement of the denture base away from the ridge than when implants are placed distally, such as in the premolar regions. The results of this in vitro study indicate that implants placed at the canine (#2/4) and 1st premolar sites (#1/5) may be an effective therapeutic protocol for use in implant-retained overdenture therapy.
Discussion - Part II

The present in vitro study investigated the effect of implant location, distribution, and number on the retention and stability of a simulated prosthesis. To the knowledge of the authors of this publication, no studies have evaluated the effect of varying implant location, distribution, and number upon in vitro dislodging forces of a simulated 1, 2, 3, or 4 implant overdenture prosthesis. The results of this study indicate that implant location, distribution, and number affect in vitro retention and stability of an implant overdenture.

The current in vitro study reveals that vertical retention increases with increasing implant number and distribution. In the vertical pull tests, the single implant reported the lowest mean retentive values and steadily increased as implant number was increased. The largest increase occurred when comparing single implants versus two; retention doubled for most systems. This increase in retention was statistically significant (p < 0.001) and potentially be clinical significant as well. The highest values were reported in the 4-implant model. The type of attachment affects the effect of vertically applied forces. Locator and Ball attachments showed similar trends as compared to each other. In these attachment types, the highest level of force was required to dislodge the 4-implant group and the lowest was the one implant group. Locator attachments showed no statistical difference in retention between canine and 2nd premolar 2-implant groups (p <
and Ball attachments only had a moderate statistical difference between these two (p < 0.05). Both systems also saw statistically significant increases between narrowly spaced and widely space implants in the 3-implant model (p < 0.001). This effect was not clearly shown in the ERA an O-Ring groups indicating that the design of the attachment significantly affects its retentive behavior (p < 0.001). O-Ring groups, furthermore, showed a decrease in retention in the widely spaced 3-implant group versus the narrowly spaced 3-implant group. ERA groups showed no significant difference between 2 widely spaced implants and 3 widely space implants in regards to retention (p > 0.05). When comparing attachment systems within the single implant groups, Locator and Ball attachments had retentive values that would be sufficient for patient satisfaction. All two, three, and four attachment systems tested would be sufficient for patient satisfaction.

Horizontal displacement forces increase with increasing implant number and distribution except in the two implant model. In the oblique pull tests, the results varied tremendously depending on the type of attachment utilized. The ERA attachments showed only moderate increases in oblique stability when comparing one, two and three implant groups. A non-significant decrease in stability occurred when three narrowly spaced implants were compared to two widely spaced implants (p > 0.05). The O-Ring attachments saw a significant and substantial increase in stability in two implants at the canine locations compared to a single, midline implant (p < 0.001). The two widely spaced implants, however, showed no statistical difference compared to the single
implant (p > 0.05). This trend was repeated when comparisons were made between three narrowly spaced versus widely spaced implants. In the O-Ring system, three narrowly spaced implants gave higher stability values than three widely spaced implants. The Locator and Ball attachment systems were similar in their trends for horizontal stability values. Both systems showed significant increases in stability when additional implants were added (p < 0.001), however, in the Ball attachments, no statistical difference was found between two implants and three narrowly spaced implants (p > 0.05). Both systems reported significantly higher horizontal stability with three widely spaced implants and four implants (p < 0.001).

The difference in resiliency of attachment systems may have had an effect upon horizontal stability of the simulated overdenture prosthesis. Similar trends were noted between Locator and Ball attachments, as these two systems were significantly more retentive than the ERA and O-Ring systems (p < 0.001). The design of ERA and O-Ring attachments are allow greater flexibility in their matrix/patrix interface and thus greater rotation. This finding has been illustrated previously.\(^6^7\)

In the present study, antero-posterior chain pulls were evaluated as an indirect method of determining the effect of implant location upon posterior dislodging forces. In all attachments systems tested, a general trend was determined that an increased resistance to dislodgment occurred with increasing implant number and distribution except in the three implant model. ERA attachments showed high variation between the
one implant model and the 2, 3, and 4 implant models. 2 implants at the canine locations showed statistically similar resistance to dislodgment as three implants both at the canine and premolar locations (p > 0.05). Two widely space implants at the 2nd premolar locations had values statistically similar to 4 implants (p > 0.05). The O-Ring group showed statistical differences between all groups (p < 0.05), with one implant the lowest value and 4 implants the highest. A steady increase was noted between groups 1 and 6 with the exception of group 5, the widely spaced three-implant model. This trend was also seen in the vertical and oblique tests, indicating that the O-Ring attachment system does not respond as well to wide distribution of implants. The Locator and Ball attachment systems were similar in their trends for antero-posterior stability values. Both systems showed significant increases in stability when additional implants were added (p < 0.001); however, large decreases in resistance occurred between two widely spaced implants and thee narrowly spaced implants. This value decrease was also seen in the ERA attachments.

The substantial decrease in resistance to posterior dislodging forces was evident in the three implant model; when implants were widely spaced, greater stability resulted. While this effect was also seen in the two implant model, it was especially evident in the three implant model. The proximity of the two canine implants to the midline implant creates an unstable pivoting effect that causes the posterior implant attachments to rotate more freely and disengage quickly. This phenomenon may be explained by the previous
information listed in part I in regards to rotation around the fulcrum lines. As the incorporation of more than 2 implants occurs in the test model, the anterior implants assume the role of the fulcrum as opposed to the anterior residual ridge as seen in the two implant model. When a posterior dislodging force is applied with one midline implant plus two implants located at the canine position, the resistance arm is the length between the midline implant to the line bisecting the posterior two implants. In this group, the fulcrum lies in close proximity to the resistance point, thus making for a short resistance arm. This situation may also have resulted in an unstable pivot point between the three implants were in the widely spaced groups, the forces were better distributed. Analyzing the 3-implant example where implant location is at the midline and two canines, figure 18 (A) illustrates the lever dynamics. Moving the two canine implants location distally to the 1st premolar location, as shown in figure 18 (B), the resistance arm is substantially lengthened compared to that shown in figure 18 (A).
Fig. 18. Components of a Class II lever system as applied to the 3-implant overdenture model.

The anterior implant is the fulcrum point, the implant and attachment serves as the resistance, and the power is the posterior dislodging force.
The power required to exact a similar dislodging force would be much higher in example (B) because the mechanical advantage has been reduced. This mechanical illustration may better explain the results of this study. As seen in the analysis of the antero-posterior dislodging force test, significantly higher forces were required to dislodge the prosthesis when implants were widely distributed on the test model \( (p < 0.001) \). When comparing the 3-implant model and a function of groups, moving implants from the canine location (group 4) to 2nd premolar (group 5) lengthened the resistance arm (Fig 18). By lengthening the resistance arm in this example, a reduction in mechanical advantage occurred, thus increasing the force required to lift the prosthesis from the ridge. Interestingly, this had a large effect on Locator and Ball attachment systems, most likely due to the on/off nature of these attachments. Furthermore, three narrowly spaced implants were less resistant to dislodging forces than two narrowly spaced implants. This phenomenon could be attributed to the wide area of the residual ridge fulcrum present when only two implants are present. With the addition of the third midline implant, the fulcrum becomes the attachment system. In the attachment systems, this point fulcrum creates a pivot point and high levels of instability.

Utilizing the formula illustrated in figure 14 with the measurements listed in figure 19, the following mechanical advantage ratios are determined: Group 4 = 5.0 > Group 5 = 1.2. The effect of this decrease is evident can be compared to the results of antero-posterior dislodging forces found in this study. Group 4 reported a significantly
lower dislodging force as compared to group 5 (p < 0.001), indicating that widely distributed implants may lower mechanical advantage and more force is required to dislodge the prosthesis away from the alveolar ridge. This finding is also supported by Avant’s evaluation of the effect of indirect retention upon a removable partial denture base.66

Fig. 19. Simulated overdenture test prosthesis super-imposed over model with implant positions, fulcrum and power locations illustrated. The fulcrum is single midline implant, the resistance is the line bisecting the posterior implants, and the power is a line bisecting the posterior dislodging force. RA = Resistance Arm, PA = Power Arm.

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The variation between attachment systems is of great interest when formulating conclusions regarding the effect of implant number and distribution upon retention and stability. The present study shows that attachment type affects retention and stability different by location, distribution, and number. For example, in the vertical retention test, ERA and O-Ring attachments showed similar behavior when additional widely-spaced implants were placed but were dissimilar to that of Locator and Ball attachments. Furthermore, in the antero-posterior dislodgement test, O-Ring attachments showed a reduction in resistance to dislodgement when comparing three widely spaced implants to three narrowly spaced implants. The opposite occurred in the ERA, Locator, and Ball groups indicating that for these attachments, widely spaced implants result in greater resistance to dislodgement.

The results of this study illustrate that attachment systems respond in different ways depending on their number and distribution in the edentulous arch. Therefore, if one uses 8 to 10 N of force as appropriate for retention of a prosthesis, only Locator and Ball attachments would provide sufficient vertical retention in the single implant model. Furthermore, when considering posterior dislodging forces, only Ball attachments would provide enough resistance to dislodgement. This finding may help illustrate the rationale for reports in the literature of successful treatment with a single ball overdenture. Results of this study in regards to implant distribution and number are in agreement with previous studies. As compared to the studies, this study found a significant increase
in retention and stability when implants number was increased and when implants were widely distributed (p < 0.001). The findings of the present study are in agreement with the aforementioned authors in regards to implant number and distribution.

Caution must be emphasized, however, that these findings do not take into consideration the clinical reality of management of edentulous patients. The results of this study indicate that 1, 2, 3, or 4-implants may produce effective in vitro retention and stability of an overdenture prosthesis. The testing performed is limited with specific conditions and methods and does not completely replicate clinical situations as the implant overdenture clinical reality is much more complex than a laboratory setting can replicate. Furthermore, the findings of this study also do not account for attachment wear, resiliency, and tissue effects. While this in vitro based analysis shows a statistical difference between groups, long-term comparative prospective controlled studies are needed to reach agreement on an accepted treatment concept. Factors such as the type and location of implants placed, quality and quantity of bone, and type of superstructure should be part of these studies.

Clinicians often base their selection of implant location and attachment system empirically on expected retentive qualities. Scientifically evaluating these factors allow the clinician to formulate a comparison of implant location to retention and stability of an implant-retained overdenture prosthesis. The results of this in vitro study indicate that single ball attachments, and 2, 3, or 4 widely spaced implants may be an effective
therapeutic protocol for use in implant-retained overdenture therapy. A single implant and ball attachment may provide adequate retention for implant overdenture treatment but only for Ball attachments. The present study found that two widely-spaced implants may be as effective as three narrowly spaced implants. Four parallel implants provide the most retention and stability; however, it is possible that this situation may result in excessive retention.
Chapter 10: Conclusions
Conclusions - Part I

Within the limitations of this in vitro laboratory study, the following conclusions were made.

1. The interactions between attachment system, direction of force, and implant location were statistically significant (p < 0.001).

2. Vertical retention and horizontal stability of a simulated overdenture prosthesis increased with distal implant location up to the 2nd premolar.

3. Antero-posterior stability increased as implant location was placed distally.

4. Attachment type affects retention and stability differently by location. Ball attachments reported the highest levels of retention and stability.

5. Inter-implant distance had a significant effect upon retention and stability of a simulated overdenture prosthesis.

6. Retention and stability of a 2-implant simulated overdenture prosthesis is significantly affected by implant location (p < 0.001)
Conclusions - Part II

Within the limitations of this in vitro laboratory study, the following conclusions were made.

1. The interactions between attachment system, direction of force, and implant number and distribution were statistically significant (p < 0.001).
2. Vertical retention of a simulated overdenture prosthesis increased with additional widely spaced implants.
3. Horizontal stability of a simulated overdenture prosthesis increased with additional widely spaced implants except in the 2-implant model.
4. Antero-posterior stability of a simulated overdenture prosthesis increased with additional widely spaced implants.
5. Attachment type affects retention and stability differently by location. Ball attachments reported the highest levels of retention and stability.
6. A single implant and ball attachment may provide adequate retention for implant overdenture treatment. Two widely-spaced implants may be as effective as three narrowly spaced implants. Four parallel implants provide the most retention and stability.
7. Retention and stability of a simulated prosthesis is significantly affected by implant number, distribution, and position (p < 0.001).
References


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