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The in Vitro Effect of Different Implant Heights and Different Buccal-lingual Angulations on the Retentive Properties of an Attachment System in Two-implant Supported Mandibular Overdentures

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DEDICATION

“In the name of Allah, Most Gracious, Most Merciful”

This thesis is affectionately dedicated to my family who gives meaning to my life and always supports me in my efforts to make my dreams come true.

*To my father, Abdulhamid and, my mother, Fatama, for all the unconditional love, and continuous guidance, and support in pursuing higher education. “My Lord, have mercy upon them as they brought me up [when I was] small.”
(Quran 17:24)*

To my husband Khaled, for his unconditional love, support, and understanding.

To my baby sons, Suliman and Jibran who give meaning to my life.

To my brother, Omer, and Own for their love and encouragement.

To my sisters for their love, endless support and encouragement.

ABSTRACT

Purpose. The aim of this in vitro study was to evaluate the retentive properties of an overdenture attachment system when two implants were placed at different heights (0mm and 3mm) and/or different angulations (0° and 20°).

Materials and Methods. Forty sets of two implants-supported overdenture models were evaluated (N=10 for each group). An acrylic resin block was used to house the overdenture attachments (Locator[®]), while an artificial bone block was used to house the two 4.3 × 13mm internally hexed implants (Nobel Biocare). The groups consisted of the following: For Group A : (control group), implants were placed parallel to each other and at the same horizontal level; For Group B: implants were placed parallel to each other and at different heights (3mm different); For Group C: implants were placed at different angulations (20° divergence) and at same height; For Group D: implants were placed at different angulations (20° divergence) and at different heights (3mm). The height was pre-determined by the artificial bone block and different abutment collar heights were used to compensate for the difference. The angulations were determined by a digital goniometer in relation to the vertical axis. All angled implants were lingually tilted. Forty pairs of Locator[®] attachments were used and for all groups the pink nylon male was used for standardization purposes. Dislodging cycles were applied to the overdenture attachments system using a texture analyzer that was programmed to apply dislodgment forces to Locator[®] attachment system in a wet condition and to stop cycling when dislodgment force drop below 20 N. The cycles required for the retentive forces of the locator[®] attachments to drop below 20 N were recorded. Two-way ANOVA and four Independent-samples t-tests ($\alpha=0.05$) between each groups were used to analyze the difference in retentions loss among the four groups.

Results. Initial retentive forces for all groups ranged from 60N to 68N. For the main effect of height and angulations, the results of Two-way ANOVA were significant and there was an interaction between different heights and angulations of implants. The results of the Independent samples t-tests revealed significant differences for the number of cycles required for initial retentive forces to drop below 20 N between groups (C and D), (A and C), and (B and D), while there was no significant difference between groups (A and B).

Conclusions. The results of this in vitro study demonstrated that the different heights and angulations negatively affect attachment retention capacity. Groups A and B showed the greatest longevity, while group D showed the shortest longevity.

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LIST OF CONTENTS

DEDICATION.....	II
ABSTRACT.....	III
THESIS COMMITTEE.....	V
ACKNOWLEDGMENT.....	VI
LIST OF CONTENTS.....	VIII
LIST OF FIGURES.....	X
LIST OF TABLES.....	XII
I. INTRODUCTION.....	1
I a. Etiology of edentulism.....	2
I b. Consequences of edentulism.....	3
I c. Treatment options of edentulism.....	4
II. LITERATURE REVIEW.....	6
II a. Implant overdenture.....	6
II b. Patient satisfaction.....	7
II c. Implant-retained overdenture.....	8
II d. Selection of attachment system for implant overdenture.....	9
II e. Locator [®] attachment system.....	11
II f. Retentive properties of implant overdenture attachment systems.....	13
II g. Guidelines of implant placement.....	15
II h. Bone morphology.....	17
II i. Effect of implant angulations in implant overdenture.....	19

III. PURPOSE OF THE STUDY.....	22
IV. HYPOTHESIS.....	23
V. SIGNIFICANCE OF THE STUDY.....	25
VI. MATERIALS AND METHODS.....	26
VI a. The sample size.....	26
VI b. Fabrication of acrylic resin blocks.....	26
VI c. Fabrication of artificial bone blocks.....	27
VI d. Determine positions of implants, attachments, and Pindex pins....	27
VI e. Alignment of the acrylic resin and the artificial bone blocks.....	28
VI f. Implant placement.....	28
VI g. Placement of Locator [®] attachment system.....	29
VI h. Classification of groups.....	31
VI i. The Cyclic loading.....	31
VII. RESULTS.....	33
VII a. Descriptive statistical analysis	33
VII b. Hypothesis testing.....	33
VIII. DISCUSSION.....	36
IX .CONCLUSIONS	43
X. CLINICAL IMPLICATIONS.....	44
XI. RECOMMENDATIONS	45
XII. REFERENCES.....	62

LIST OF FIGURES

Figure 1: Components of implant overdenture.....	46
Figure 2: Bar and Ball attachment systems for implant overdenture.....	46
Figure 3: Ball attachment categories	46
Figure 4: Matrix component of Locator [®] attachment system.....	47
Figure 5: Patrix component of Locator [®] attachment	47
Figure 6: Nylon Male insert.....	47
Figure 7: Dual retention of Locator [®] attachment.....	48
Figure 8: The pivoting action of Locator [®] attachment.....	48
Figure 9: Angulations of Locator [®] attachment	48
Figure 10: Changing the Locator [®] nylon Male insert.....	49
Figure 11: Vertical discrepancy of alveolar residual ridge.....	49
Figure 12: Changing of residual alveolar ridge angulations.....	49
Figure 13: Fabrication of acrylic resin blocks.....	50
Figure 14: Schematic dimension of artificial bone blocks	50
Figure 15: Reference lines to determine components positions.....	51
Figure 16: Parallelism of the bone and the acrylic resin blocks	51
Figure 17: Implant placement.....	52
Figure 18: Group (A) implant positions.....	52
Figure 19: Group (B) implant positions.....	53
Figure 20: Group (C) implant positions.....	53
Figure 21: Group (D) implant positions.....	54
Figure 22: Group (A) Locator [®] abutment heights.....	54

Figure 23: Group (B) Locator [®] abutment heights.....	54
Figure 24: Group (C) Locator [®] abutment heights.....	55
Figure 25: Group (D) Locator [®] abutment heights.....	55
Figure 26: Placement of locator [®] Male component	55
Figure 27: Classification of groups.....	56
Figure 28: Assembly placement.....	56
Figure 29: Cyclic loading.....	57
Figure 30: Box-plot.....	59

LIST OF TABLES

Table 1: Demonstrates the number of cycles required for the retentive force to drop below 20 N of each sample.....	57
Table 2: The mean and standard deviation of cycles required for the retentive force to drop below 20 N for each group.....	59
Table 3: Two-way ANOVA results.....	60
Table 4: Mean and mean of time for groups	60
Table 5: 2x2 table.....	61
Table 6: Independent samples t-test results.....	61

INTRODUCTION

Edentulism is defined as the loss of all permanent teeth.¹ Edentulism has been considered a significant global public health problem affecting tens of millions of people worldwide and represents the endpoint of oral pathology.^{2,3} A study by Weintraub and Burt has shown that more than one third of the population over age 70 and more than one quarter of the population older than 65 are completely edentulous.⁴ Over the past one hundred years, there have been significant advances in the dental science, and as a result, the prevalence of tooth loss in the United States has decreased. This change was originally apparent in the 1950s.⁵⁻⁷ The two main reasons for this decrease are: the advance in restorative dentistry which made extraction of teeth an unusual alternative and caries rate declined due to fluoride using.⁵ A surveillance for edentulism indicates that between 1999-2000, only approximately 8% of US adults aged ≥ 20 years were completely edentulous.⁸

Despite this decrease in the percentage of Americans with edentulism, other authors are predicting a steady state or growth of edentulism in the next two decades. According to Douglass⁹ who discussed the question: "Will there be a need for complete dentures in the United States in 2020?", the demand for complete removable prostheses will increase for the next 20 years due to the significant growth in the US older population (79% growth in the population aged 55 years and older) along with declining access to dental care. The overall need for complete dentures will increase from 53.8 million in 1991 to 61.0 million dentures in 2020.

Etiology of Edentulism:

Edentulism is the terminal outcome of a multifactorial process involving biological processes (caries, periodontal disease, pulpal pathology, trauma, oral cancer) and non-biological factors.¹⁰ Regarding the biological etiologies of edentulism, the World Health Organization databanks indicate that caries is still prevalent in the majority of countries internationally, with some reporting 100% incidence in their populations; severe periodontal disease is estimated to affect 5% to 20% of the population.³ The non-biological factors of edentulism include education, income, economic development, urban versus rural areas, and general health. The rate of edentulism appears to be inversely related to education^{11,12} with the relative risk being approximately twice as great for those with little education compared to those with higher levels of education.^{13,14} In general, people with lower income tend to have a higher rate of edentulism.¹¹ This is likely due to the cost of treatments as full mouth extraction is typically the least expensive treatment modality.

Several countries have demonstrated a correlation of edentulism rates to rural versus urban areas, which vary from two to three times higher in rural areas. Perhaps this variation can be attributed to differences in the dentist/patient ratios between the areas.^{15,16} Despite that, complete edentulism is an international problem particularly in the 65 years and older age groups; the condition does not appear to be concentrated in developing countries.¹⁷ The overall health and the health behavior have been shown to be linked with edentulism. Several reports have described a lower incidence of edentulism in healthy patients,¹⁸⁻²⁰ while patients with smoking habits,²¹ or frail

elderly adults²² are more likely to be edentulous. Based on the Douglass study and the etiologies of tooth loss that are still uncontrolled, the need for complete denture is not likely to decrease in the near future, and the edentulism remains an important public health problem both in the United States and worldwide.³

Consequences of Edentulism:

Oral health is an integral part of the systemic health, and poor oral health directly affects the quality of life. According to the World Health Organization, edentulism is defined as a physical impairment because important body parts have been lost, a disability because tooth loss limits people in performing at least two essential tasks of life (speaking and eating), and a handicap because significant changes are needed to compensate for such deficiencies.²³ The masticatory system is critical for the individual to replace the body's nutrients and maintain optimal overall health. Besides the reduction of the residual alveolar ridge which is considered one of the most important oral sequelae of edentulism,^{24, 25,10} several studies have demonstrated that edentulous patients have a poorer diet than their dentate counterparts.^{26, 27} Shimazaki et al,²⁸ compared the physical activity and mortality between groups of edentulous institutionalized patients without dentures to the partially edentulous patient (>20 teeth) over 6-year and the study has shown that the edentulous patients with no replacement dentures experienced a decline in physical ability and an increase in mortality rates. Also the edentulism has been considered as a risk factor for coronary disease,²⁹ hypertension and stroke,³⁰ obstructive apnea,³¹ and some types of cancer.³² With these sequelae of edentulism, the necessity to replace missing teeth in the edentulous population seems apparent.

Treatment Options of Edentulism:

There are three options to treat an edentulous patient: conventional complete denture, fixed implant prosthesis (4 to 6 implants are placed in to support a fixed partial denture) or removable implant supported and/or retained prostheses (2 to 4 implants are placed to support and/or retained an overdenture).³³ The choice of treatment depends on many factors such as the amount of alveolar bone resorption, the patient's satisfaction with existing prosthesis, as well as the financial status and the patient's overall health.

The maxillary complete removable prosthesis provides a better retention, support and stability compared to the mandibular complete removable prosthesis. The major advantage in the maxilla is the presence of palate and generally substantial residual alveolar ridge height. The support area for the mandibular ridge represents 1/3 of that found in the maxilla. In addition, the rate of resorption in mandible is approximately four times greater than in the maxilla.³⁴ Edentulous patients with severe alveolar bone resorption in the mandible may experience problems with conventional dentures such as insufficient stability and retention, therefore an alternative treatment should be considered. Implant-retained overdentures have shown superiority over complete dentures especially in the mandible in several ways, including patient's satisfaction, comfort, chewing ability, social and sexual activities, and quality of life.^{35,36,17} Also, studies have shown major advantages over implant-supported fixed partial dentures such as the reduced number of implants.³⁷ The prostheses retained by implants and supported by soft tissue generally require fewer implants than do totally implant-supported fixed prostheses and as result offer patients an economic alternative,³⁷ an easier surgical procedure, and an easier restorative technique due to application of prefabricated attachments.³⁸

Among factors involved in the selection decision, the finances probably are the most important. As an example, the Dutch National Health Service reimburses most of the costs of implant overdentures whereas there is no reimbursement for fixed restorations. On the other hand, In Sweden, there is no difference in reimbursement between removable and fixed implant restorations.³⁹ Such initiatives by funders will undoubtedly make implant treatment more attainable and heighten the prospect that implant overdentures will replace conventional dentures as the preferred mode of rehabilitation of edentulous patients. The implant supported and /or retained mandibular overdenture has been largely investigated. Based on a comprehensive literature reviewed by a panel of experts, the 2002 McGill symposium established the mandibular overdenture supported by two implants as the first choice of treatment for edentulous mandible.⁴⁰

LITERATURE REVIEW

Implant Overdenture:

An overdenture is defined as any removable dental prosthesis that covers and rests on one or more remaining natural teeth, the roots of natural teeth, and/or dental implants.¹ Mechanical attachments fixed in teeth roots to enhance the stability and retention of an overdenture have been used for nearly a century. The concept of attachment fixation for over-denture originated in Switzerland around 1898 and Gilmore popularized it 100 years ago.⁴¹ The use of roots to stabilize, support, and retain the overdenture is now replaced by the use of implants. By utilizing implants to support the overdenture we can avoid complications like caries and periodontal disease that are the common when we use roots to stabilize, support and retain the overdentures.

Over the course of the past one hundred years, there have been significant advances in the science and art of Prosthetic Dentistry, but few would disagree that the impact of osseointegration in the last 30 years has been nothing short of momentous.^{42, 43} The implant removable overdentures are either implant -supported overdentures (three to four implants) or implant-retained and soft tissue supported overdentures (one or two implants). In implant-retained overdentures, some hinging movement is allowed by using two implants but if more than two implants are used, there will be no rotational axis and the overdenture support comes mainly from the implants.⁴⁴ Zitzmann et al,⁴⁵ compared the cost of treatment between implant-supported overdentures and implant-retained overdentures, and they found that the implant-retained overdentures over 3 years is cost-effective.

Patient Satisfaction:

Implants have offered a great service to edentulous patients, but the critical change has been achieved in completely edentulous patients particularly with atrophic mandibles and/or maxillae. A five year prospective randomized study by Gotfredsen and Holm⁴⁶ of overdentures retained by two implants in the mandible showed a success rate of 100% which was independent from the attachment system used. Meijer et al⁴⁷ found that after five years, patients with mandibular overdenture retained by two implant had higher satisfaction scores than complete denture patients. And this result was confirmed by another randomized study by Raghoobar et al⁴⁸ who found that the patients with implant overdenture had higher satisfaction scores than patients with conventional complete denture even with patients who had undergone prerprosthetic surgery. Implants in the edentulous mandible have become the standard treatment for patients who are not satisfied with the result of conventional complete denture. Feine et al⁴⁹ compared a group with fixed implant prosthesis with another group with removable implant prosthesis. The authors found that 50% of patients chose the removable design for ease of cleaning and esthetics.

Several investigators have reported a high level of satisfaction in patients wearing implant-retained overdentures.⁵⁰⁻⁵³ MacEntee et al⁵⁰ studied patient satisfaction with two-implant mandibular overdentures using a visual analogue scale (VAS) from 0 to 100; overall satisfaction in the bar-clip attachment group was 93 one month after fitting and 96 after two years, and in the ball-spring group 94 and 93 respectively. Patients who received implant-retained overdentures expressed a high degree of satisfaction, both overall and for all indicators (aesthetics, speech, mastication,

stability of the prosthesis and self-esteem) independently of age, sex, length of follow-up, rehabilitated jaw, number of implants per overdenture, splinted or non-splinted, and the type of attachment.⁵¹

Rashid et al⁵² evaluated two hundred and three edentulous patients satisfaction with their new mandibular conventional dentures or implant overdentures retained by two implants by using 100-mm visual analogue scale questionnaires. The authors found that patients with implant overdentures reported significantly higher ratings of overall satisfaction, comfort, stability, ability to speak and ability to chew despite their relatively higher cost, than those who choose new conventional dentures. In a crossover clinical trial, Cune et al⁵³ evaluated patient satisfaction with two-implant mandibular overdenture treatment with different attachment types after 10 years of function, and they found that the patients appreciation of their implant-retained dentures was and remained high over time.

Implant-retained Overdentures:

Both types of removable implant overdentures have three components (Fig. 1): (1) the implant (fixture); (2) the abutment, which contains the keyway or key attachment component, depending on the system used; and (3) the over-denture, which contains the counterpart attachment.⁵⁴

Many attachments are now available for use in implant-retained overdentures. The design of an implant-retained overdenture can be carried out in two ways (Fig. 2). Splinting approach includes connect the implants with a ridge interconnecting bar which incorporates an attachment mechanism for overdenture retention (bar attachment). In another approach, implants are not connected to each other (non-

splinting), and the retention mechanism is provided via abutment, which incorporates some form of retentive mechanism (ball attachments).^{44,55,56} The ball attachments are divided into two groups (Fig. 3): (1) Extra-radicular, in which the key element projects from root surface or implants, and (2) Intra-radicular, in which the key element projects from base of the denture and engage in a depression within the root or implant.⁵⁷

Selection of Attachment Systems for Implant Overdenture:

Several investigators attempt to define the indications for the use of bar or ball attachments. In general, attachment systems indications are dependent upon the retention required; jaw morphology, implant angulations, and patient overall health. It has been assumed that bar connector provides a rigid support for overdentures similar to that provided by fixed prosthesis and also provides primary stability by splinting implants, so it can be selected when a higher degree of retention is required^{58,59} such as in anatomically compromised cases with short implant as a result of severe bone resorption.⁶⁰ Kenny and Richards⁶¹ evaluated the photo-elastic stress patterns produced by implant-retained overdentures with different attachment systems. They found that ball attachments transferred less stress to implants than the bar attachments. Another in vivo study by Menicucci et al,⁶² measured the force distribution differences between ball and bar attachment systems. They concluded that the ball attachments provide greater stability and more even distribution of load than bar attachments. The load was increased on the working-side abutment when the bar-anchored attachment was used.

The ball attachments are indicated in edentulous patients with limited vertical space.⁶⁰ Sufficient space for the prosthetic components of the implant attachment system is critical. Inadequate space for prosthetic components can result in an over-contoured prosthesis, excessive occlusal vertical dimension, fractured teeth adjacent to the attachments, attachments separating from the denture, fracture of the prosthesis, and overall patient dissatisfaction.⁶³ The ball attachments are also indicated in patients with narrow mandibular arch (v-shape arch) as a straight bar between two implants would likely be interfered with tongue function. For patients with dexterity problems magnet attachments are recommended as they are easy to insert and remove.⁵⁸ The angulations of the implants can be an important factor when choosing attachments. Implants with poor angulations are often splinted with a bar.^{64, 56} But based on Wiemeyer et al ⁶⁶ study, the stud attachments can also be used for divergent implants.

The ball attachment is less technique sensitive,⁶⁷ less costly,⁴⁵ and makes peri-implant hygiene easier for older patients; the potential for mucosal hyperplasia reportedly is more easily reduced with ball attachments,⁶⁸ which makes it attractive to both the clinician and patients. In addition, the ball attachments can be used with an existing conventional denture. The old conventional denture is directly altered to accommodate implant overdenture attachments, the treatment is usually easier and more predictable (less alteration of the denture base).^{69,70} The simplicity and all of the above advantages of ball attachment system has made it widely used, particularly with mandibular implant overdentures.

Locator[®] Attachment System:

The Locator[®] attachment system (Zest Anchors) is an attachment system that does not use the splinting of implants and consists of a matrix and a patrix. The manufacturer refers to female and male components to describe the system. The matrix (female) is composed of a Locator[®] abutment made of Titanium with a Titanium-nitride coating that is available in different collar heights. It is inserted into an implant and torqued to a specific force with a specific torque wrench. Clinically, the matrix remains intraorally (Fig. 4).

The patrix is a metal cap with an interchangeable nylon insert. The patrix engages the matrix to provide a sufficient retention force to stabilize and retain the overdenture. Clinically, the patrix is embedded in the overdenture and the patient is able to manually engage and disengage the overdenture (Fig. 5). The nylon insert comes in different colors and each has a different retention value (Fig. 6) to be used according to the clinical situation. The clear, pink or blue nylons are recommended for angulations varying from 0° to 10°. Their retention capabilities are described to be respectively 2268, 1361, and 680 grams. The green, orange, and red nylons are recommended for implant angulations varying from 10° to 20°. Their respective retention capabilities are in a range of 1361, 907, and 680 grams.

There are six advantages to the Locator[®] system advertised by the manufacturer:⁷¹

1- *low vertical height*: Its design features the benefits of the minimal height requirement; it requires less interarch space than other attachments as the total height of the locator[®] attachment (abutment plus male) is only 3.17mm on externally hexed implant, and 2.5mm on a non-hexed implant. It also has a greater metal cross-section when it is soldered on a bar which improves the bar's strength. This permits its use in

tight inter-arch cases without compromise in bar strength that normally would occur when the height of the cast bar is reduced to create more occlusal space.

2- *Self aligning*: The patrix and matrix are attached together without precise alignment; this self aligning allows a patient to easily seat their overdenture without the need for accurate alignment of the attachment components.

3- *Durability*: The *Dual Retention* (combination of external and internal retentive mating surfaces) is patented and has been incorporated in the clear, pink and blue nylon inserts to increase the retention surface area ensuring long lasting retention life in the 0° to 10° situation (Fig. 7).

4- *The pivoting action*: The retentive nylon male remains in static contact with the female socket while its metal denture cap has a full range of rotational movement over the male (Fig. 8). This design allows a resilient connection for the overdenture without any resulting loss of retention.

5- *They can be used in non-parallel implant situations*: The clear, pink and blue can compensate for up to 10° of divergence from vertical (20° between implants), while the green and red inserts can be used for up to 20° of divergence from vertical (40° between implant, Fig. 9). The internal extension is absent from the green and red insert to compensate for the angulations.

6- *Easy to change*: Unlike traditional attachments, you do not have to grind the Locator[®] male out of the overdenture and then pick up the new component using self-cure acrylic resin. Instead, stainless steel housing is permanently mounted into the overdenture to precisely position the male. You simply remove the old male out of its housing with an easy to use tool, and then snap in a new male (Fig. 10).

Retentive Properties of Implant Overdenture Attachment Systems:

Retention has been recognized as an important concept of removable prosthetic dentistry since 1913.⁷² Denture retention is defined as the resistance of a denture to vertical and tensional stresses, or the resistance of a denture to removal in a direction opposite that of its insertion.¹ Several investigations were conducted to determine the retentive force of a large array of commercially available attachment systems for mandibular two- implants overdentures.^{58, 73-77.}

Petropoulos et al⁵⁸ compared the retentive forces of five attachment systems (Nobel Biocare bar and clip, Nobel Biocare ball, Zest anchor, Zest magnet, and sterngold ERA) on implant-retained overdenture model. A single acrylic resin model was fabricated by placing two implants in canine areas and then they randomly connected the patrx components to be tested. Acrylic overdenture analogs were fabricated to fit over the overdenture model and by using Instron machine, the dislodging tensile forces were applied in two directions (vertical and oblique). The results showed that the Nobel Biocare bar and clip was the most retentive compared with other four attachments for both directions with a mean values and standard deviations of (20.62 ± 4.96 N) in vertical direction and (19.18± 1.62N) in oblique direction. The Sterngold ERA (gray) was the next most retentive with a mean values and standard deviations (7.18 ±3.29N) in vertical and (6.46± 2.00N) in oblique direction, followed by Zest anchor, and Nobel Biocare ball. The Zest magnet was the least retentive with mean values and standard deviations (1.25±.068 N) in vertical direction and and (1.40±.19N) in oblique direction.

Petropoulos and Smith⁷³ conducted another study under similar conditions and experimental design to compare the retentive force and stability of the next generations of attachments (Nobel Biocare standard ball, Nobel Biocare 2.25mm diameter ball, Zest anchor, Zest anchor advance generation (ZAAG), Serngold ERA orange, and Serngold ERA white). The dislodging forces were applied in three direction (vertical, oblique, and anterior-posterior). The results showed that the ZAAG was the most retentive attachment with vertically and obliquely directed dislodging forces (37.2 N and 27.2N respectively), and Nobel Biocare standard was the most retentive in anterior-posterior directed forces (34.6N) but was not statistically different from ZAAG attachment systems.

Michelinakis⁷⁴ evaluated the effect of three different inter-implant distance (19, 23, and 29mm) on the retention characteristics of mandibular two implant overdenture (Hader bar/white clip, Hader bar/yellow clip, Hader bar/red clip, Ball, and magnet attachment). Inter-implant distance was found to have an effect on red and yellow plastic clips for Hader bars. The red and yellow plastic clips on Hader bars produced statistically higher retention when they were placed apart. Retention value for red plastic at 19mm was 12.6N and at 29mm was 20.73N. For the rest of attachments tested, the retention remained unaffected by inter-implant distance and the magnet attachments showed a least retentive force.

There is little information in the literature concerning the Locator[®] attachments. Chung et al⁷⁵ compared the retention characteristics of Locator[®] LR pink and LR white attachments to other attachment systems (ERA white, ERA gray, SpheroFlex ball, Hader bar and metal clip, and three type of magnet). The dislodging force was applied by a universal testing machine in vertical direction. The results suggested that the gray ERA showed the highest retention (35.24 N) followed by the LR white

Locator[®] (28.95N). The magnet attachments from three different manufacturers were the least retentive which is consistent with previous findings of Petropoulos study.⁷³ The changes in the retentive forces of the yellow Hader clips and the white and green Locator[®] attachments were tested over 20 pulls on a universal testing machine.⁷⁶ Results showed that there was difference in the initial maximum dislodging force between all three types of attachments. The green Locator[®] attachments showed the highest maximum dislodging force and the greater percent reduction in maximum dislodging force, followed by white Locator[®] attachments. The Hader clips showed the least percent reduction and least maximum dislodging force.

The commercially available attachments systems offer a wide range of retentive forces. The weakest attachment was the magnet with initial retentive force of 3N, the strongest one was the ball attachment with a retentive force of 85N based on a study conducted by Setz et al.⁷⁷ In general, published research agrees that the magnet is the least retentive attachment and because of this retentive mechanism, Petropoulos et al⁵⁸ suggested using it in bruxer patients (less forces are delivered to the implants) and in patients with dexterity problems who may have difficulty inserting and removing the overdenture.

Guidelines of Implant Placement:

Successful prosthetic design of the implant overdenture requires three-dimensional implant position and angulations. There are general guidelines pertaining to the implant position and angulations for the two implant retained overdenture design. First, it is recommended to position implants in the area of cuspid/lateral incisor site.⁷⁸ Implants in the anterior mandible should be placed in the canine or lateral positions. Implants positioned in the anterior area of the mandible reduce the tendency for the

denture to rotate around the fulcrum provided by the denture. The denture base may lift when the patient incises anteriorly if the implants are placed too far distally. The two-implants overdenture with stud attachments are not constrained by specific inter-implant space requirements, while when two-implants overdenture with a bar is used, an inter-implant distance of no more than 15 mm to 20 mm is needed to accommodate at least one clip and for metallurgic considerations.⁷⁸ Second, implants should be positioned within the bulk of the denture to preserve the structural integrity of the prosthesis, which usually corresponds to the center of the alveolar ridge.

Third, clinicians have stated that implants planned for use with overdentures must be parallel to one another to obtain predictable attachment retention and complete seating of the retentive elements and for prevention of future maintenance problems.^{66, 69-70, 79-80} The non-parallel implants could impede passive insertion of the prosthesis and lead to premature wear of ball or stud-type prosthetic components. This supposition is further reinforced by the literature provided by implant manufacturers.^{81, 82} It has been suggested that although divergence of about 10° between two unsplinted implants can usually be tolerated, excessive wear will result from wide divergences or convergences, leading to a decrease in retention of the implant overdenture components.^{83, 84}

It has also been suggested that the implants be positioned as perpendicular to the occlusal plane as possible so that they are loaded axially without producing a bending moment.⁸⁵ Despite the use of a surgical guide to orient implant placement, factors like surgeon's skills and the patient cooperation can alter the final position of the implants. In addition, the optimal placement of implants is also dependent on the anatomy and morphology of the bone which means that, in clinical practice, all of the

foregoing guidelines may be not fulfilled. The bone loss of the residual ridge is one of the most common challenges the clinicians have to face before implant placement.

Bone Morphology:

The edentulous arches are vital structures present during the patient's life regardless of tooth presence or function. The residual ridge is formed following tooth extraction, and remodeled mainly by resorption. Reduction of the residual alveolar ridge (RRR) is a continuous process following tooth extraction and is considered one of the most important oral sequelae of edentulism.^{24,25} A number of factors can affect progressive bone loss of dental arch before and after tooth loss. After tooth extraction, both local and systemic factors have been implicated in the etiology of RRR. Local factors, such as occlusal trauma (poorly fitting complete dentures) and time of edentulism have been consistently reported as its prominent cause.^{34, 86-88} Furthermore, there are systemic factors that control bone turnover such as diet, age sex, and hormonal status of the individual.⁸⁶

Based on the article of Pietrokovski et al,⁸⁹ mandibular body arch length ranges from 53 to 67 mm (mean 61mm), whereas the width of the residual ridge crest extends from 1 to 18 mm. Knife-edge ridges were found 75% in the incisor area, 38% in the premolar areas and 15% in the molar regions. Flat-rounded ridges were found 25% in the incisor area, 62% in the premolar region, and 85% in the molar regions. The edentulous crest measured at the incisor, premolar, and molar regions was inclined lingually to the mental protuberance anteriorly and to the mandibular base posteriorly. This lingual inclination of the crest to the mandibular base varied from 99° to 120° (9°-30° to vertical axis).

The cylindrical geometry of dental implants requires certain anatomic prerequisites for the preparation of the recipient site during surgery to provide suitable conditions for healing. The size of the selected implant depends on the height, width, and angulations of available bone. Over the years, various strategies have been proposed to overcome the anatomic and physiologic limitations of implant placement. Surgical interventions including guided bone regeneration with or without a tenting screw,^{90, 91} distractive osteogenesis,⁹² sinus augmentation,⁹³ and nerve transposition⁹⁴ have been suggested. However, despite the presence of adequate vertical dimensions to place implants, the alveolar bone crest often exhibits compromised horizontal proportions; Thus, in cases where the implant sites exhibit a horizontal alveolar ridge defect (buccal-lingual bone loss) the clinician may consider resecting the higher portion of the ridge to facilitate implant placement (alveoplasty). Alternatively, the implant may be placed using the lingual bone crest as a reference for the implant margin in combination with a bone-augmentation procedure. From the frontal view, same procedure may be done if there is a vertical ridge height discrepancy between right and left side of residual alveolar bone due to horizontal bone loss of one side (Fig. 11).

The bone resorption of the residual ridges does not only affect the vertical and horizontal dimensions of the ridge. It also has an effect on the angulation of alveolar residual ridge to the vertical axis after tooth extraction. The healing process following tooth removal apparently resulted in more pronounced resorption on the buccal than on the lingual/palatal aspects of the ridge. Pietrokovski & Massler⁹⁵ studied the amount of tissue that was lost after unilateral tooth extraction and used plaster casts models for the dimensional assessments. The authors concluded that the buccal bone plates both in the maxilla and the mandible were resorbed considerably more than the

corresponding palatal/ lingual bone walls and that the center of the ridge, as a consequence, shifted palatally/lingually.

Placing implants in the lower anterior region in the edentulous mandible can be deceptive. A natural tendency is to place implants perpendicular to the horizontal plane of the edentulous ridge and incline implants to the labial simulating direction of natural tooth should be avoided. When a clinician simulates placement to natural tooth direction, a perforation of the lingual plate might happen. After tooth loss, the alveolar ridge angulation changes from labial (Blue line) to lingual inclination (Green line) in the edentulous mandible (Fig. 12).

Effect of Implant Angulations in Implant Overdenture:

Gulizio et al⁹⁶ investigated the retention of gold and titanium overdenture attachments when placed on ball abutments positioned off axis. Four ball abutments were hand tightened onto ITI dental implants and were placed in an aluminum device that allowed positioning of the implants at 0, 10, 20, and 30 degrees from a vertical reference axis. Gold and titanium matrices were coupled to ball abutments at various angles and then subjected to pull tests at a rate of 2 mm/s. The study showed that there was a negative effect of angulations on the retention of gold matrices, but not on the retention of titanium matrices.

Ortegon et al⁹⁷ compared the retentive properties of spherical attachments over time when used with different implant and attachments angulations in a cyclic testing mode using universal testing machine. Five different angulations between implants and attachments were evaluated: Group-1: (0-0), 0-degree implants and 0-degree

attachments; Group-2: (10-0), 10-degree implants and 0-degree attachments; Group-3 : (15-0), 15-degree implants and 0-degree attachment; Group-4 : (10-10), 10-degree for implants and attachments; Group-5: (15-15), 15-degree for implants and attachments. The results showed that Group 1(0-0) had the highest retention mean value (21.31N) and the Group 5 (15-15) that consisted of divergent attachments coupled with divergent implants had the lowest retention mean value (17.3N). Group 1 (0-0) was found to have no significant difference when compared to Group 3 (15-0) which consisted of parallel attachment and non parallel implants. This observation substantiates the observation of Wiemeyer et al⁶⁶ on divergent gold attachments processed following a nonparallel implant scenario. The authors outlined the importance of aligning the attachments to the path of insertion and withdrawal of the prosthesis in a parallel approach in both parallel and non-parallel implant scenarios.

To date, only a few reports are available on retentive properties of overdentures utilizing the Locator[®] attachment system under non-parallel implants scenarios. Evtimovska et al⁷⁶ conducted a study to compare the peak load-to-dislodgment and the percent reduction in peak load-to-dislodgment of two different attachments systems (Hader bar-clip, Locator[®] system). The attachments were placed in acrylic resin blocks which were seated on other acrylic resin blocks containing a Hader bar or two Locator[®] abutments with different angulations. The green nylon inserts were used with angulated implants (20° mesial-distal angulations). The samples were subjected to 20 consecutive pulls using a universal testing machine. The results showed that the green Locator[®] attachment exhibited the greatest percent reduction in peak load-to-dislodgment in this study. The authors attribute that to implant angulations (20° divergence). The angulated implants increase the rate of wear of the green nylon inserts upon removal from the Locator[®] abutments.

Al-Ghafli et al⁹⁸ evaluated the effect of cyclic dislodgement on the retention properties of overdentures using the Locator[®] attachment system when two implants were placed at different mesio-distal angulations. Acrylic resin blocks were used to simulate the residual ridge and overdenture. The two implants were placed at different angulations (0, 5, 10, 15, or 20 degree divergence) in acrylic resin blocks that seated with other acrylic resin blocks that contain the Locator[®] attachment matrix (white nylon males were used for parallel implants and green nylon males were used for angulated implants). The dislodging cycles were applied using texture analyzer. The authors found that the implant angulations contribute significantly to the rate of retention loss, therefore the implants should be placed parallel to each other and perpendicular to the horizontal plane for the nylon component of the attachment system evaluated to retain its retentive capacity for a longer period of time.

To date, no data exists on the effect of different implant heights and different implants buccal-lingual angulations due to vertical and horizontal discrepancy of mandibular residual ridge, as a result of unequal bone loss, on the retentive properties of Locator[®] attachment in two implant-supported overdentures.

PURPOSE OF THE STUDY

To evaluate the retentive properties of Locator[®] attachment system placed on two implants placed at different heights (0mm, 3mm) in implant-supported mandibular overdenture.

To evaluate the retentive properties of the Locator[®] attachment system placed on two implants placed at different buccal-lingual angulations (0°, 20°) in implant-supported mandibular overdenture.

HYPOTHESIS

Null Hypothesis:

- 1- There is no difference in the retentive properties of the Locator[®] attachments in two-implant supported overdentures between implants that are placed at same height and implants that are placed at different heights due to vertical discrepancy of mandibular residual ridge.
- 2- There is no difference in the retentive properties of the Locator[®] attachments in two-implant supported overdentures between implants that are placed parallel to each other and implants that are placed at 20 degree buccal-lingual angulations due to lingual inclination of mandibular residual ridge after teeth extraction.
- 3- There is no interaction between the retentive properties of Locator[®] attachments in two-implant supported overdentures when implants are placed at different heights and at different buccal-lingual angulations.

Alternative Hypothesis:

- 1- There is a difference in the retentive properties of the Locator[®] attachments in two-implant supported overdentures between implants that are placed at same heights and implants that are placed at different heights due to vertical discrepancy of mandibular residual ridge.
- 2- There is a difference in the retentive properties of the Locator[®] attachments in two-implant supported overdentures between implants that are placed parallel to each other and implants that are placed at 20 degree buccal-lingual angulations due to lingual inclination of mandibular residual ridge after teeth extraction.

- 3- There is an interaction between the retentive properties of Locator[®] attachments in two-implant supported overdentures when implants are placed at different heights and at different buccal-lingual angulations .

Our Hypothesis:

- 1- The retentive properties of Locator[®] attachments placed on two implants placed at different height (3mm) will be less than the retentive properties of Locator[®] attachment placed on two implants placed at same height in two-implant supported overdenture.
- 2- The retentive properties of the Locator[®] attachments placed on two implants placed at 20 degree buccal-lingual angulations will be less than the retentive properties of Locator[®] attachment placed on two implants placed parallel to each other in two-implant supported overdenture.
- 3- There is an interaction between implant heights and angulations. The Locator[®] attachment system placed on two implants placed at different height (3mm difference) and different angulations (20°) will be the least retentive in this study.

SIGNIFICANCE OF THE STUDY

The results of this study could affect the decision of the clinician on placement of implants at different heights or different buccal-lingual angulations and selection of an appropriate attachment system for two-implant supported overdenture.

MATERIALS AND METHODS

A. Sample Size:

The number of samples per group was calculated by using nQuery (version 7.0) based on previous study.⁹⁸ Using a type I error rate of $\alpha=0.05$, a sample size of N=10 per group yields over 90% power for both height and angulations.

B. Fabrication of Acrylic Resin Blocks (Overdentures):

Forty models of two-implant supported overdenture were fabricated. Two rectangular metal boxes with internal dimensions of 60×15mm and 10mm thickness were fabricated for this study as shown in (Fig. 13). The bottom of the box was removable to allow easy removal of block. Vaseline was applied by brush to inner surface of metal boxes to facilitate removal of acrylic block from box. Autopolymerizing polymethyl methacrylate (PMMA) clear acrylic resin (Dentsply Caulk, Dentsply International, Milford, USA) was used for this study. Acrylic resin powder was mixed with monomer using the powder/liquid ratio recommended by manufacturer and then poured into boxes. The boxes were placed in a compression chamber using three bars of pressure for 15 minutes. This acrylic resin block was used to simulate the implant supported overdentures and to house the overdenture Locator[®] male attachments. Forty 60×15×10mm acrylic resin blocks were fabricated and divided into four groups of 10 blocks each.

C. Fabrication of Artificial Bone Blocks (Mandible).

Laminated test blocks were ordered from Sawbones[®] to simulate the mandible. These blocks are primarily used as an alternative test medium for human cancellous and cortical bone. The cellular rigid polyurethane foam simulates the cancellous bone (with density 7.5 pcf, and cell size 0.5-2.5 mm) and the fiber filled epoxy sheet simulates the cortical bone (with 4mm thickness). Laminated test block dimensions in this study are 60 mm in length and 15mm in width for all four groups. The height was 30mm for Groups A and C. It 30mm in one half (30mm of the length) and 27mm in the other half (30mm of the length) for Groups B and D to simulate the 3 mm difference in alveolar residual bone height due to unequal bone resorption (Fig. 14). These blocks were used to house the dental implants.

D. Determine Positions of Implants, Attachments, and Pindex Pins:

The following reference lines were drawn on bone blocks to determine positions of implants, and repositioning pins (Fig. 15):

- a) Line (1): a horizontal reference line to determine the buccal-lingual angulations of implant on bone block.
- b) Line (2): two vertical reference lines (one for each implant) were drawn to determine the inter-implants distance and to determine the mesial-distal angulations of each implant. The two lines were drawn 22mm apart.
- c) Line (3): two vertical reference lines (one for each repositioning pins) were drawn 3mm from edges of bone block to determine location of Pindex pins.

Similar reference lines were drawn on acrylic resin blocks to determine positions of Locator[®] metal housing and pins.

E. Alignment of The Acrylic Resin block and The Artificial Bone Block:

The parallelism of bone and acrylic resin blocks was controlled by using pindex machine and pins:

Two pin holes (3mm in diameter) were drilled using Pindex machine (Coltène/ Whaledent, Inc) in the exact location determined previously by drawing on the artificial bone blocks (line 3), then the pins (Coltène/ Whaledent, Inc) were stabilized in the holes by friction within the bone. The collar of pin was flushed with base of bone block. Two pin holes (3mm in diameter) were drilled in acrylic resin block using Pindex machine in the exact location determined previously by drawing (line 3). Afterward, the artificial bone block with pins was aligned with the acrylic resin block (Fig. 16).

F. Implant Placement:

Tri-channel connection straight implants with 3mm collar, 4.3 diameter and 13 mm length (Replace select straight implant RP, Nobel Biocare, CA, USA) were used in this study. Following the manufacturer's drilling sequence (fig. 17), two implants were placed by using a slow-speed hand piece connected to a surgical drill unite (Osseo set, NobelBiocare, CA,USA) and before continuing to next drill sequence, the implant angulations was checked using a direction indicator. When placing the

implant, one groove on the Implant Driver was aligned perpendicular to buccal/facial wall to ensure ideal prosthetic abutment orientation. Two dental implants are usually considered the minimum number necessary for mandibular implant overdenture treatment, allowing the mucosa and implants to provide support, retention, and stability for the prosthesis.¹⁰⁰ The two implants were placed 22 mm apart (this is the distance between two implants if placed in the canine area).¹⁰¹

According to their groups the implants were placed at different heights and angulations. For Group A (Fig. 18) the implants were placed parallel and at the same height. The parallelism of the alignment was verified with digital goniometer (Gottlieb Nestle GmbH, Dornstetten, Germany) in relation to the horizontal axis. For Group B (Fig. 19) the implants were placed parallel to each other and at different heights (3mm difference). For group C (Fig. 20) the implants were placed at the same height with different buccal-lingual angulations (20°). For group D (Fig. 21) the implants were placed at different heights (3mm) with different buccal-lingual angulations (20°).

G. Placement of Locator[®] Attachment System:

The Locator[®] implant abutments (Locator, Zest Anchors, Escondido, CA, USA) were tightened to the implants with manual torque wrench (Nobel Biocare) according to manufacturer's instructions (20 N). It is preferred that Locator[®] attachment components are placed at same level. Therefore, different implant abutment cuff heights were used (N=80) to compensate the 3mm height difference in bone block and different angulations:

For group A: Locator[®] implant abutment cuff heights (1mm, 1mm) (Fig. 22).

For group B: Locator[®] implant abutment cuff heights (0mm, 3mm) (Fig. 23).

For group C: Locator[®] implant abutment cuff heights (1mm, 1mm) (Fig. 24).

For group D: Locator[®] implant abutment cuff heights (0mm, 4mm) (Fig. 25).

A white block-out spacer was placed over the head of each Locator[®] implant abutment. The spacer is used to block out the area immediately surrounding the abutment. The space created will allow a resilient connection of prosthetic components. A Locator[®] metal housing with black processing male was inserted into each Locator[®] implant abutment. The black processing male maintains the overdenture in the upper limit of its vertical resiliency during the processing procedure. The black male is 0.2mm taller than the standard retention inserts. Two holes were drilled in acrylic resin blocks in the exact location determined previously by drawing (line 2) for placement of the locator[®] attachment male components. The holes were deep enough to ensure that there are no contact between acrylic block and metal housing. Vaseline was applied on the surface of bone block except locator male. Auto-polymerizing acrylic resin (Dentsply Caulk, Dentsply International, Milford, USA) was mixed and poured into the holes. Afterward, the two blocks (acrylic resin block and bone block) were aligned by using pins and allowed the resin to polymerize for 15 minutes (Fig. 26). After the acrylic resin has been cured, a bur was used to remove excess acrylic and polish the denture base before changing to the final male. The black processing male components were removed by using Locator male removal tool and the Pink nylon male components (N=80) were inserted by using Locator male seating tool. For standardized purposes the pink nylon male components were used for all four groups.

H. Classification of Groups:

The two-implant supported overdenture models were divided into four groups (Fig 27):

Group A: Ten implant- supported overdenture models with two parallel implants at same height and same Locator[®] abutment height (1mm, 1mm).

Group B: Ten implant- supported overdenture models with two parallel implants at different heights (3mm difference) and different Locator[®] abutment heights (0mm, 3mm).

Group C: Ten implant- supported overdenture models with two non-parallel implants (20° BL) at same height and same Locator[®] abutment height (1mm, 1mm).

Group D: Ten implant- supported overdenture models with two non-parallel implants (20° BL) at different heights (3mm) and different Locator[®] abutment heights (0mm, 4mm).

I. Cyclic Loading:

The assembly (acrylic resin block attached to the bone block via Locator[®] attachments) was placed in a plastic container filled with saliva substitute (A.S Saliva orthana, Kemisk fabrik, Denmark). Then it was mounted only into the lower grips of cyclic loading machine. The cross arm was brought down until the grips can surround the acrylic block and they were tightened onto upper section of acrylic resin block (Fig. 28). The probe control was used to move the upper clamp to a position where the forces on load cell are very close to zero in order to eliminate any forces that would be created from hand tightening. Dislodging cyclic forces were applied in a

vertical direction at a cross-head speed of 50mm/min to the overdenture attachment system using a texture analyzer (TA.XT2i Texture Analyzer; Stable Micro Systems Ltd, Godalming, Surrey, UK) (Fig. 29). This cross-head speed has been reported to approximate clinically relevant movement of the denture away from the edentulous ridge.¹⁰²

According to studies by Caldwell et al¹⁰³ that has shown that a mandibular denture would require a retaining force of 15 to 20 N for chewing, Walmsley et al^{104,105}, and Petropoulos et al^{58, 73} It would be logical to assume that an initial retentive force of 20 N is sufficient for overdentures in the edentulous mandible to maintain in position. Consequently, retention loss was defined as the number of cycles required for the dislodgement force to drop below 20 N.⁹⁸ Therefore the texture analyzer was programmed to apply dislodgment force to Locator[®] attachment system in a wet condition and to stop cycling when retentive forces drop below 20 N. The cyclic loading machine was connected to a computer and appropriate software (Exponent 32, Version 5.101, Stable Micro Systems Ltd) was used for collection of data and analysis of the retention reduction. At the end of the testing, the loss of retention was tested manually to ensure that retention was lost.

Patients under normal circumstances place and remove overdenture prosthesis four times each day, (in the morning (placement), after breakfast, after lunch, after dinner (removal and replacement), and before bedtime (removal)).¹⁰⁶ Based on this assumption; from the number of cycles we can estimate the time required to maintain the attachment system by the equation: Days = Number of cycles / 4. By this way we convert number of cycles to time. The statistical analysis was performed using the SPSS (version 18). Two -way ANOVA ($\alpha=0.05$) and Independent samples t-tests ($\alpha=0.05$) were used to analyze the difference in retention loss among the four groups.

RESULTS

The number of cycles required for the retentive force to drop below 20 N for each sample were collected by soft ware and presented in (Table 1).

Descriptive Statistical Analysis:

As shown in (Table 2), Group D (Implants were placed at different heights and different buccal-lingual angulations) showed the highest rate of retention loss, where it took 2.3 years for retentive forces to drop below 20 N. Group A and B showed the least rate of retention loss, where it took 3.35 years for group A and 3.78 years for group B. The initial retentive forces among the four groups were close to each other. The number of cycles required for the retentive force to drop below 20 N for each group were presented in a box-plot (Fig. 30).

Hypothesis Testing:

The results of the Two -way ANOVA ($\alpha=0.05$) for the number of cycles required for the retentive forces to drop below the 20 N were presented in (Table 3). Histogram of residuals was normally distributed and Leven's test was performed ($p=.205$). The null hypothesis was not rejected and each group has about the same SD.

For the main effect of heights, the result of the two-way ANOVA was significant ($F=7.502$, $p = .010$) and indicated that there is a significant difference among the groups for the number of cycles required for the retentive force to drop below 20 N in

implants-supported overdentures. The groups with same height (Group A and C) are more retentive than groups with 3mm abutment height difference (Groups B and D) (Table 4). For the main effect of angulations, the results of the Two-way ANOVA was highly significant ($F= 65.067$, $p<.001$) and indicated that there is a significant difference among the groups for the number of cycles required for the retentive forces to drop below the 20 N in implants-supported overdentures. The groups with parallel implants (Group A and B) are more retentive than groups with 20° buccal lingual angulations (Group C and D) (Table 4).

There is an interaction between the heights and angulations ($F=15.487$, $p<.001$).

Therefore, four Independent samples t-tests (Table 6) were performed to compare the means of each two groups (Table 5). Kolmogorov-Smirnov test was performed for each group and the results showed that the data was normally distributed for each group (all p-values more than .05 and the null hypothesis was not rejected).

1- Comparison of groups with different implant heights when implant angulations is 0° (Group A, B):

The result of Independent samples t-test between Groups A and B was not statistically significant ($t=-.726$, $p=.477$). Group B (Parallel implants at 3mm height different) demonstrated the greatest number of cycles before reaching the 20 N level in this study, but was not significantly different from the Group A (Parallel implants at same height). The difference in the mean between Group A and B was 211 cycles (52 day).

2- Comparison of groups with different implant heights when implant Buccal-lingual angulations is 20° (Group C, D):

The result of Independent samples t-test between Groups C and D was highly significant ($t=5.887$, $p<.001$). Group C (non-parallel implants at same height) demonstrated a greater number of cycles before reaching the 20 N level (more retentive) than Group D (non-parallel implants at 3mm height different). These groups were significantly different from each other.

3- Comparison of groups with different implant angulations when implants height difference is 0mm (Group A, C):

The result of Independent samples t-test between Groups A and C was significant ($t=2.656$, $p=.016$). Group A (Parallel implants at same height) demonstrated a greater number of cycles before reaching the 20 N level (more retentive) than Group C (non parallel implants at same height). These groups were significantly different from each other.

4- Comparison of groups with different implant angulations when implants height difference is 3mm (Group B, D):

The result of independent samples t-test between Groups B and D was highly statistically significant ($t=9.543$, $p<.001$). Group B (Parallel implants at 3mm height different) demonstrated a greater number of cycles before reaching the 20 N level (more retentive) than Group D (non-parallel implants at 3mm height different). These groups were significantly different from each other.

DISCUSSION

The present in vitro study investigated the effect of different implant heights and different angulations on the retentive properties of Locator attachments. The results indicated that the main effect of different heights between implants in mandibular two implant-supported overdentures was statistically significant and the first null hypothesis was rejected. The second null hypothesis was rejected as the results of this study indicated that the main effect of different buccal lingual angulations between implants in mandibular two implant-supported overdentures was statistically significant. Also, the third null hypothesis was rejected as the comparison of the different implant height effect on the retentive properties of locator[®] attachments depends on implant angulations and the comparison of the different implant angulations effect on the retentive properties of locator attachments depends on implant heights. There is an interaction between height and angulations of the implants. Therefore, the Independent samples t-samples tests were performed to compare the means of each two groups.

Most of the studies that evaluated retentive properties of the attachment system in implant-supported overdenture used static pull only. A few studies evaluated the retention of attachment system of implant overdentures in a cyclic loading mode. In an attempt to best simulate a clinical scenario in which the attachment system undergoes repeated insertion and removal cycle over time, the cyclic loading machine was used and programmed to stop cyclic when retentive force drop below 20 N. The 20 N force was used as reference for retention loss based on previous literature.^{58,73, 103-105} This is the minimum retentive force required to maintain the denture in place.

In addition, artificial saliva and an artificial bone block were used. All the previous studies evaluated the retentive properties of attachment systems in implant overdentures by using an acrylic resin or dental stone model to simulate the mandible. A crosshead speed of 50mm/min was used. This speed has been reported to approximate clinically relevant movement of the denture away from the edentulous ridge.¹⁰²

The results of current study showed that the attachment system retentive forces recorded at the first pull were noticeably higher than subsequent values and then a gradual decrease in the retentive forces in all four groups has been demonstrated. All groups show same pattern of retention loss rate which was in agreement with the plastic deformation curve. The mean initial retentive forces of each group were close to each other and at the range of 65 N. The retentive forces of attachment system found in this study were in agreement with those reported in the previous literature. Setz et al⁷⁷ reported that retentive force of ball attachment range from 3 to 85 N.

In clinical use, the amount of retentive force that are necessary to satisfy the patient is a compromise. However, retentive force has to be high enough to prevent displacement of denture. On the other hand, forces must not exceed a certain level or destructive effects on the periodontal ligament may occur during removal of denture.¹⁰⁷ The retention is of great importance for patient's satisfaction. Burns et al¹⁰⁸ found a strong patient preference for the attachment with superior retention. Therefore retentive forces and loss of retention are important data in the selection of an appropriate attachment for patient's edentulous mandible with implant overdenture. The present study evaluated the effect of implant angulations on the retentive properties of the Locator[®] attachment in mandibular two implant-supported overdenture. Compared to the number of studies conducted for implant overdenture,

very few studies were conducted to evaluate effect of implant angulations on the retentive properties of attachment system in implant overdentures. Clinicians and implant manufacturers^{81,82} have stated that parallelism of implants in implant overdentures is important to obtain predictable attachment retention and complete seating of the retentive elements and to prevent premature wear of the involved components.^{66, 69-70,79-80}

Unfortunately, in clinical practice is difficult to achieve implant parallelism as a result of bone resorption and surgeon's skills. Due to unilateral tooth extraction, the buccal bone plates both in the maxilla and the mandible are resorbed considerably more than the corresponding palatal/lingual bone walls and that the center of the ridge, as a consequence, shift palatally/lingually.⁹⁵ The lingual inclination of the bone crest to the mandibular base varies from 9°-30° to vertical axis⁸⁹ and it has been suggested that divergence or convergences higher than 10 degree will usually result in excessive wear.^{83,84} Because of the above two reasons, 20 degree lingually tilted implant was used in current study.

The current in vitro study showed that buccal lingual angulations of implant has a negative effect on the retentive properties of attachment system in mandibular two implant overdentures which is consistent with previous studies. Al-Ghafli et al⁹⁸ evaluated the effect of different mesio-distal angulations (0°,5°,10°,15°,20° diverge) on the retention of locator attachment system (Green nylon male) in two implant-supported overdenture and found that the implant angulations negatively affect attachment retention longevity. Ortegon et al⁹⁷ found that there was a decrease in retention in the group with divergent implant and divergent attachment compared to the group with ideal situation (parallel implant and parallel attachment), while there was no significant difference in retention when compared the group with divergent

implants and parallel attachment (resilient spherical attachment) to the group with ideal situation. As a result of these findings, it can be assumed that angulated implants in current study may be managed by using the green nylon male or angulated abutment. According to the manufacturer, the green nylon component can be used to correct implant angulations up to 20° of divergence from vertical and 40° between implants.

To date, no study in implant overdenture has evaluated the effect of different implant heights on the retentive properties of attachment system. Vertical ridge height discrepancy between right and left side of residual alveolar ridge is occurred due to unilateral tooth extraction. The vertical height discrepancy can be compensated in by increasing the thickness of acrylic resin base of overdenture or by using different abutment heights. In the current study, the 3 mm height difference between the two implants was compensated by using different abutment cuff heights. The 3 mm height difference has been chosen because less than 3 mm would not be significant. The biomechanics of crown height space are related to lever mechanics. As a result, any increase in the crown height space (CHS) increases the amount of force and subsequently increases the mechanical complications associated with implant prostheses.¹⁰⁹ According to M. Marinbach¹¹⁰ there are two crown height space with implant overdenture. The first CHS is the distance from to the crest of the bone to the attachment system (abutment height) and the higher the first CHS the more the forces applied to the implants. The second CHS is the distance from the attachment to the occlusal plane and the higher the second CHS the more the forces applied to the attachment. In the present study the first CHS of locator attachment 3mm for Group B and D and the second CHS is 10 mm for all four groups (thickness

of acrylic resin blocks). Therefore higher lever action to the attachment exists than to the implant.

The results of current study suggested that the effect of different heights of implants was not statistically significant when implant were placed parallel to each other (Group A and B). The difference in means between Group A and B was 211cycle that is equivalent to 52 days (1M/20D). This finding can be contributed to the vertical direction of forces. Occlusal loads transferred down the long axis of the implant are not considerably affected by crown length,¹¹¹ while there was a significant difference of different implant heights when implants were placed at 20 degree diverge (Group C and D). From this finding, it can be concluded that implant angulation has a negative effect on implant height. The non-axial loading due to non-parallel implant creates moments of force with high stress concentrations at cervical area (implant/abutment connection).¹¹² This may has a negative effect on the stability of the implant/abutment assembly and attachment wear rate. Wear-induced changes in the dimensions of the attachment nylon components and this was implicated as the primary cause for the loss of retention.^{77,113-116} In current study, a distinct wear pattern was observed in the pink nylon inserts.

The negative effect of buccal-lingual angulations was more prominent when the implants were placed at different heights. The difference was highly significant when compared between the group of different implant angulations at same height and the group of different implant angulations at different heights. Implants are nonmobile; therefore, when non-axial forces are applied to an implant, they are concentrated at the implant abutment junction and the crest of the supporting bone creates a significant lateral moment in both angulated implants (Groups C and D).^{117,112} The lateral forces are magnified in direct relationship to the crown height (Group D).¹¹⁸

Excessive occlusal overload due to an increased moment arm (abutment height) may cause mechanical failure of the prosthetic components.^{118,119}

Occlusal management for two-implant supported overdentures is difficult, because the two-implant supported overdenture (implant-retained overdenture) is dependent on both soft tissue and implant support. Ichikawa et al,¹²⁰ showed that the different displacement between implant (20–30 μm) and soft tissue (about 500 μm) leads to stress concentration at the implant in implant-supported overdenture and this increases as the thickness of mucosa increases. In the current study, the overdenture models were rested on the artificial bone blocks without simulating the mucosa. Overdenture models (acrylic resin blocks) for different implant heights Groups (B and D) were seated on the higher portion of the artificial bone blocks. While in clinical situations, the 3 mm height different in residual alveolar ridge is occupied by mucosa. When the load is applied, prosthetic intrusion may be greater with a thicker and softer mucosa and cause more stress concentration on the attachment system.¹²⁰ Therefore it can be assumed that the effect of different implants height may be more noticeable in clinical situation even in parallel implant scenario.

Based on assumption of four times placement/removal of prosthesis,¹⁰⁶ the result of present study indicated that the attachments can retain their retention retentive force for 3.64 years when implants are placed parallel to each other and at same horizontal level, while for 2.32 years when implants were lingually tilted and at different heights. The restorative dentist can provide the patients with information regarding the recall and maintenance of the attachments. However the accurate prediction is difficult since other factors such as the number and the position of implants and the type and the material of the attachments are important as well.

Limitations of the study:

This in vitro study had several limitations. The design of the research model did not simulate a complete overdenture set-up. In the oral cavity, the soft tissue upon which the overdenture rests is resilient. The resiliency of the soft tissue may affect the load on the attachments and therefore can affect their retentive values. The thermal cyclic was not performed and only the withdrawal of the attachments along the path of insertion (vertical direction) was investigated. The dynamic nature of overdenture function in the complex biomechanical environment of the oral cavity has proven challenging to replicate in a laboratory setting.

CONCLUSIONS

Within the limitation of this study, the following conclusions were drawn:

- 1- Different implant heights did not have a significant effect on retentive properties of overdenture attachment system evaluated when two implants were placed parallel to each other (Group A and B).
- 2- Different implant heights have a significant effect on retentive properties of the overdenture attachment system evaluated when two implants were placed at 20 degree buccal-lingual angulations (lingually tilted) (Group C and D).
- 3- Different implant angulations have a highly significant effect on the retentive properties of overdenture attachment system evaluated when two implants were placed at same height (Group A and C).
- 4- Different implant angulations have a highly significant effect on the retentive properties of overdenture attachment system evaluated when two implants were placed at 3mm different heights (Group B and D).
- 5- Group D with 3mm difference height and 20 degree buccal-lingual angulations showed the shortest period of time before attachment system components required replacement.

CLINICAL IMPLICATIONS

Our data suggested that implants in two implant-supported mandibular overdenture should be placed parallel to each other and at the similar level in order to prolong the life of retentive components by preventing premature attachment wear due to lateral forces created by lingually tilted implants or increasing abutment heights.

RECOMMENDATIONS

Further in vitro studies using different buccal-lingual, different abutment height and multidirectional forces are needed to draw definite conclusion regarding effect of different implant heights and different buccal-lingual angulations on the retentive properties of Locator[®] attachment system in implant-supported overdenture. In addition, using green nylon males or angulated abutments to compensate the implant angulations might have an impact on the retentive properties of Locator[®] attachment system.



Figure 1: Components of Implant Overdenture; the implant (fixture); (2) the abutment, which contains the keyway or key attachment component, depending on the system used; and (3) the over-denture, which contains the counterpart attachment



Figure 2: Bar and Ball Attachment Systems for Implant Overdenture. Splinting approach includes connect the implants with a ridge interconnecting bar (bar attachment). In another approach, implants are not connected to each other (non-splinting), and the retention mechanism is provided via abutment (Ball attachments).

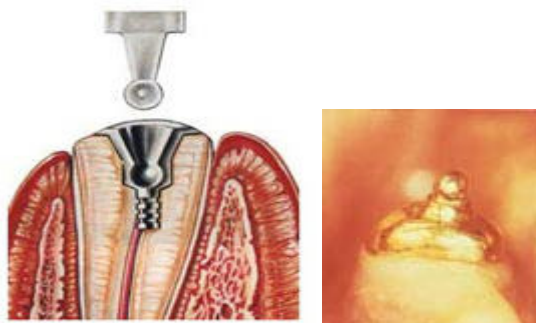


Figure 3: Ball Attachments Categories. (1) Extra-radicular, in which the key element projects from root surface or implants, and (2) Intra-radicular, in which the key element projects from base of the denture and engage in a depression within the root or implant.



Figure 4: Matrix (abutment) Component of Locator® Attachment System. The matrix (female) is composed of a Locator® abutment made of Titanium with a Titanium-nitride coating that is available in different collar heights. Clinically, the matrix remains intra-orally.



Figure 5: Patrix (male) Component of Locator® Attachment System. The patrix is a metal cap with an interchangeable nylon insert. Clinically, the patrix is embedded in the overdenture and the patient is able to manually engage and disengage the overdenture.



Figure 6: Nylon Male Insert. It is available in different color according to degree of retention.



Figure 7: Dual Retention of Locator® Attachment. Combination of external and internal retentive mating surfaces has been incorporated in the clear, pink and blue nylon inserts, while the internal extension is absent from the green and red insert to compensate for the angulations.

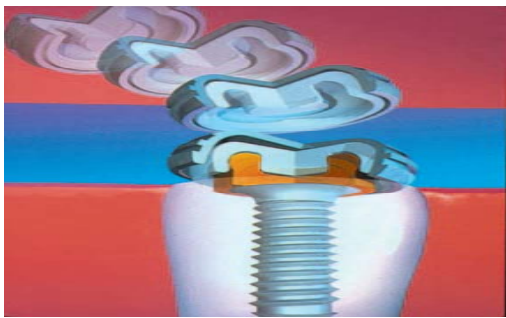


Figure 8: The Pivoting Action of Locator® Attachment. The retentive nylon male remains in static contact with the female socket while its metal denture cap has a full range of rotational movement over the male.

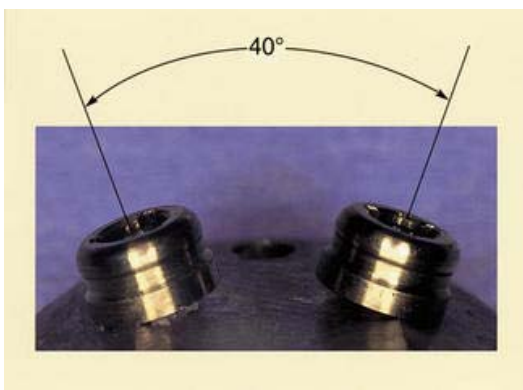


Figure 9: Angulations of the Locator® Attachment. The green and red inserts can be used for up to 20° of divergence from vertical and 40° between implant.

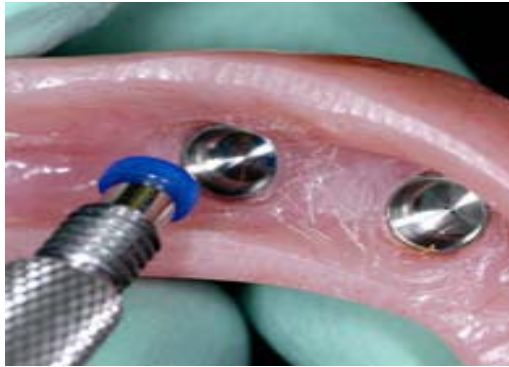


Figure 10: Changing the Locator[®] Nylon Inserts. Stainless steel housing is permanently mounted into the overdenture to precisely position the male. You simply pry the old male out of its housing and then snap in a new male.



Figure 11: Vertical Discrepancy of Alveolar Residual Ridge. The alveolar residual ridge often exhibits vertical ridge height discrepancy between right and left side.

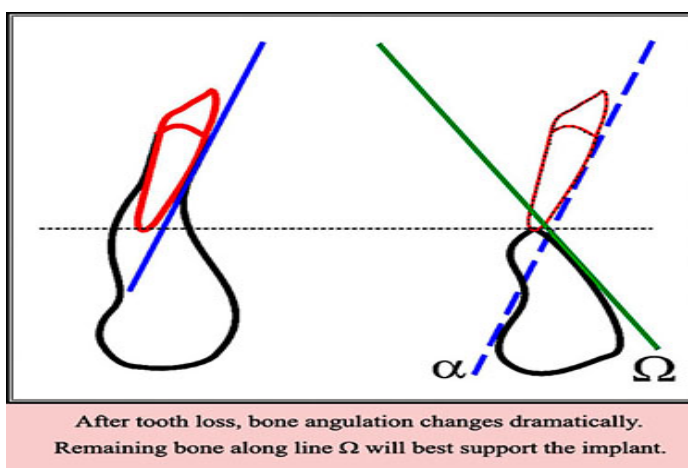


Figure 12: Changing of the Residual Alveolar Ridge Angulation. After tooth loss, the alveolar ridge angulation changes from labial (Blue line) to lingual inclination (Green line) in the edentulous mandible.

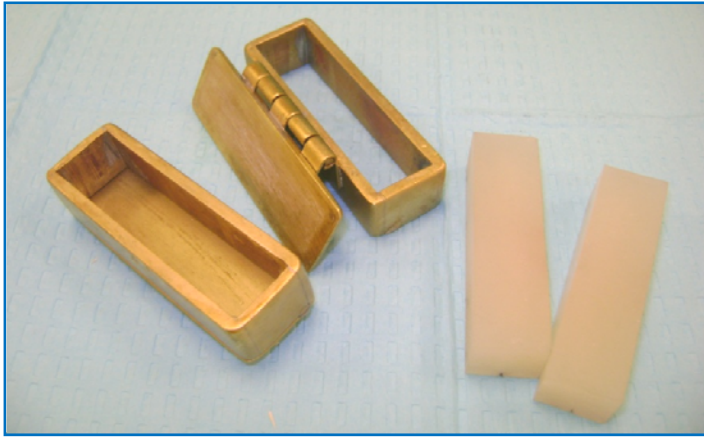


Figure 13: Fabrication of Acrylic Resin Blocks. Acrylic resin blocks were fabricated by pouring acrylic resin mixture into metal boxes with internal dimensions of 60×15×10mm.

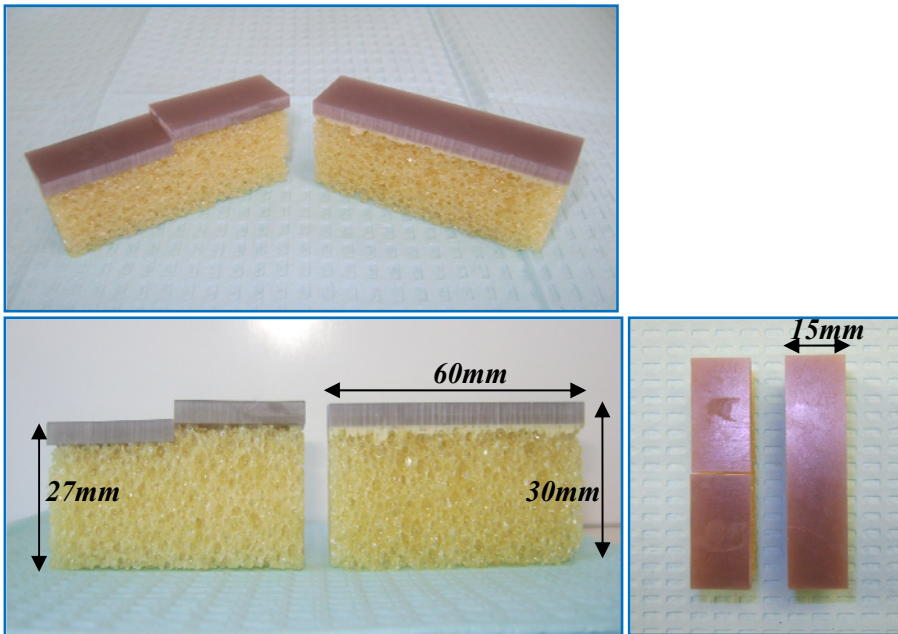


Figure 14: Schematic Dimensions of Artificial Bone Test Block: 3mm difference in height to simulate bone resorption.

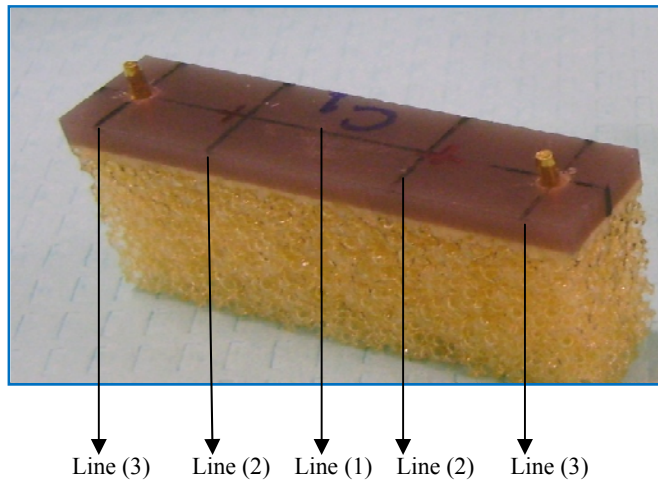


Figure 15: Reference Lines to Determine Components Positions. Line (1): a horizontal line to determine the BL angulations of implant; Line (2): two vertical lines were drawn to determine the inter-implants distance and to determine the MD angulations of each implant; Line 3: two vertical lines were drawn to determine location of Pindex pins.

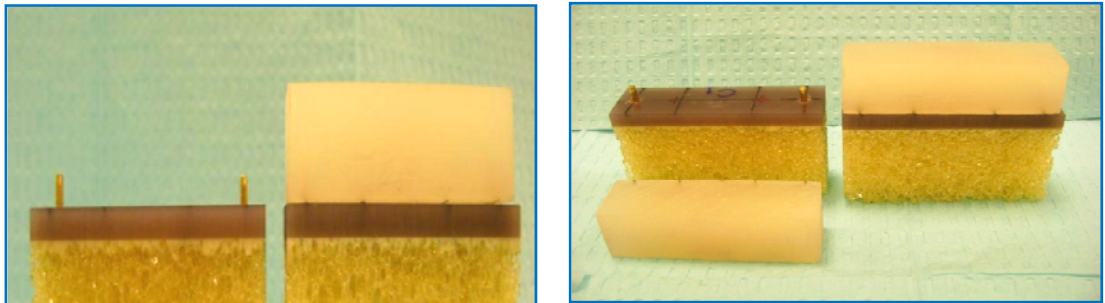


Figure 16: Parallelism of the Bone and the Acrylic Resin Blocks. The parallelism of the bone and the acrylic resin blocks was controlled by using repositioning pins.

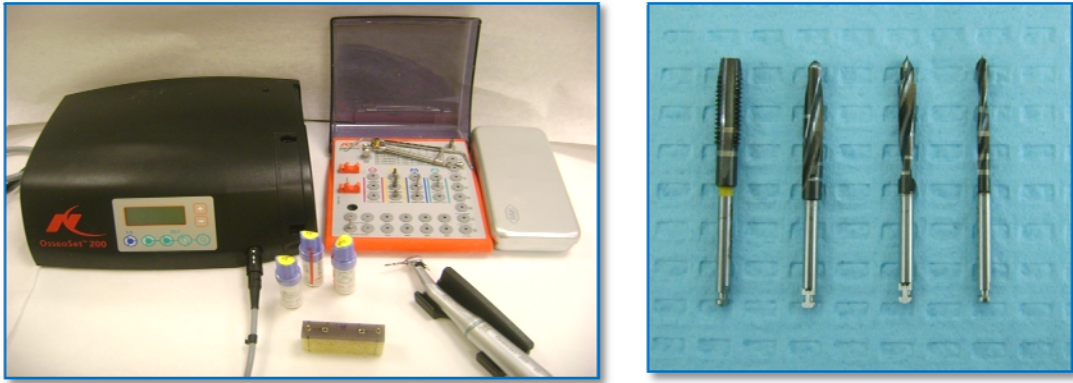


Figure 17: Implant Placement; A Nobel Replace straight surgical kit was used to place implant following the manufacturer's drilling sequence (drill Ø 2.0, 2.8, 3.2, 4.3). All drills are marked to enable you to prepare the site to the correct depth (13mm).

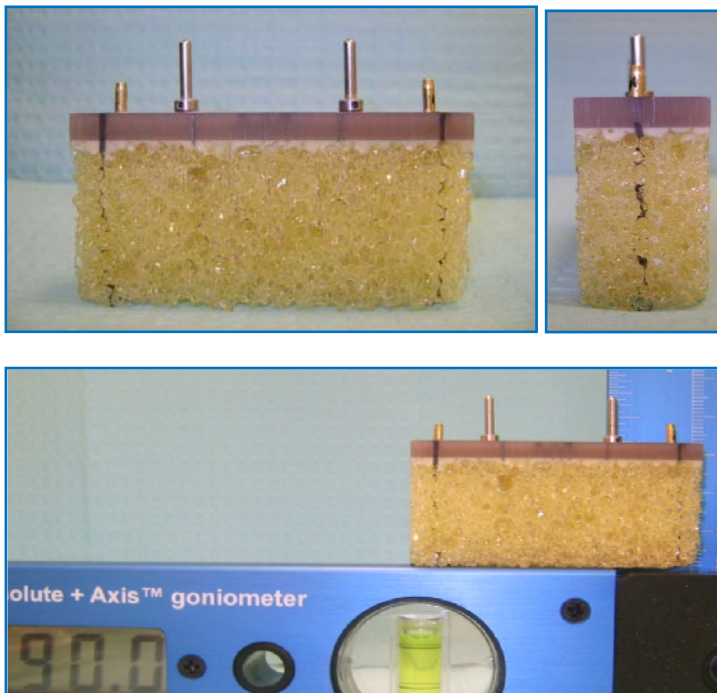


Figure 18: Group (A) Implant Positions: The implants were placed parallel to each other and at the same height. Angulations and heights of the implants in frontal and lateral views.

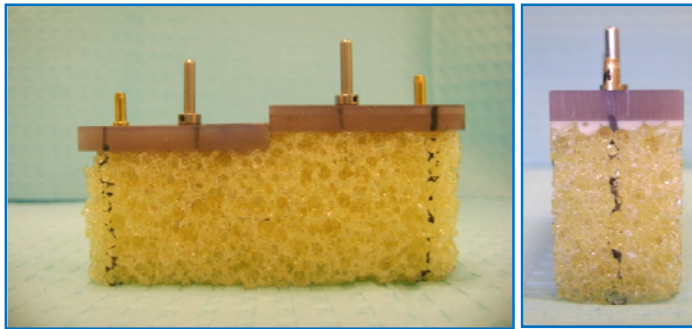


Figure 19: Group (B) Implant Positions: The implants were placed parallel to each other and at different heights (3mm). Angulations and heights of the implants in frontal and lateral views.



Figure 20: Group (C) Implant Positions: The implants were placed at the same height with different buccal-lingual angulations (20°). Angulations and heights of the implants in frontal and lateral views.



Figure 21: Group (D) Implant Positions: The implants were placed at different heights (3mm) with different buccal-lingual angulations (20°). Angulations and heights of the implants in frontal and lateral views.

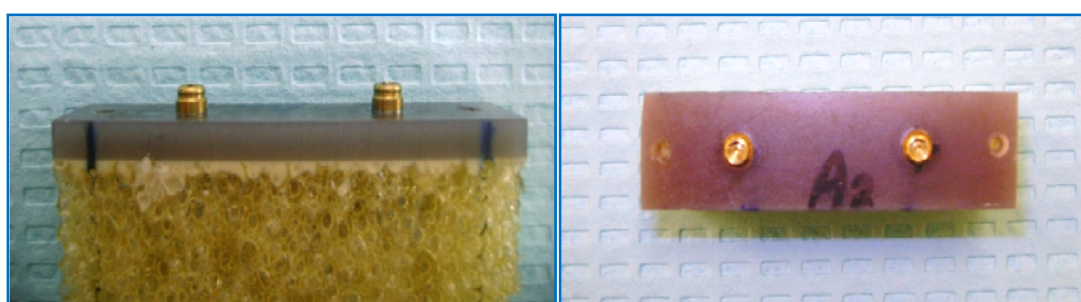


Figure 22: Group (A) Locator® abutment heights (1mm, 1mm).

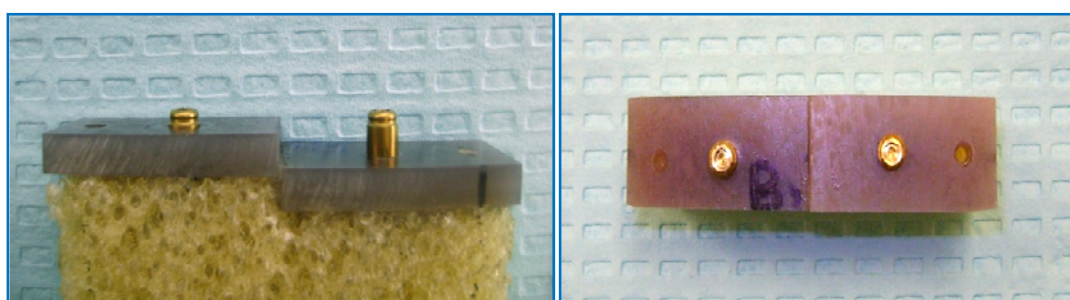


Figure 23: Group (B) Locator® abutment heights (0mm, 3mm).

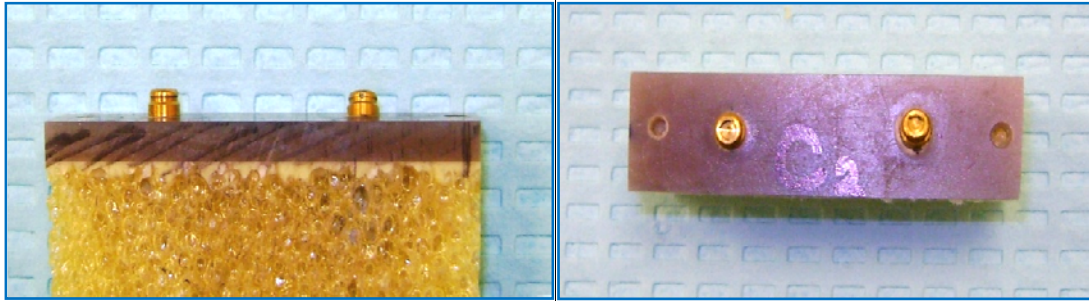


Figure 24: Group (C) Locator® abutment heights (1mm, 1mm).

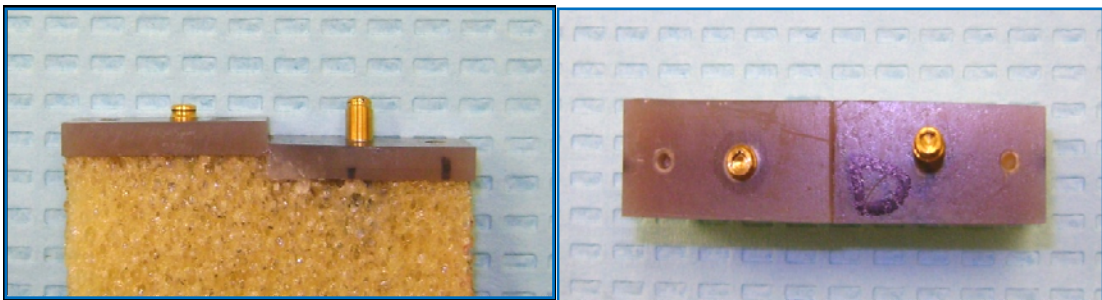


Figure 25: Group (D) Locator® abutment heights (0mm, 4mm).

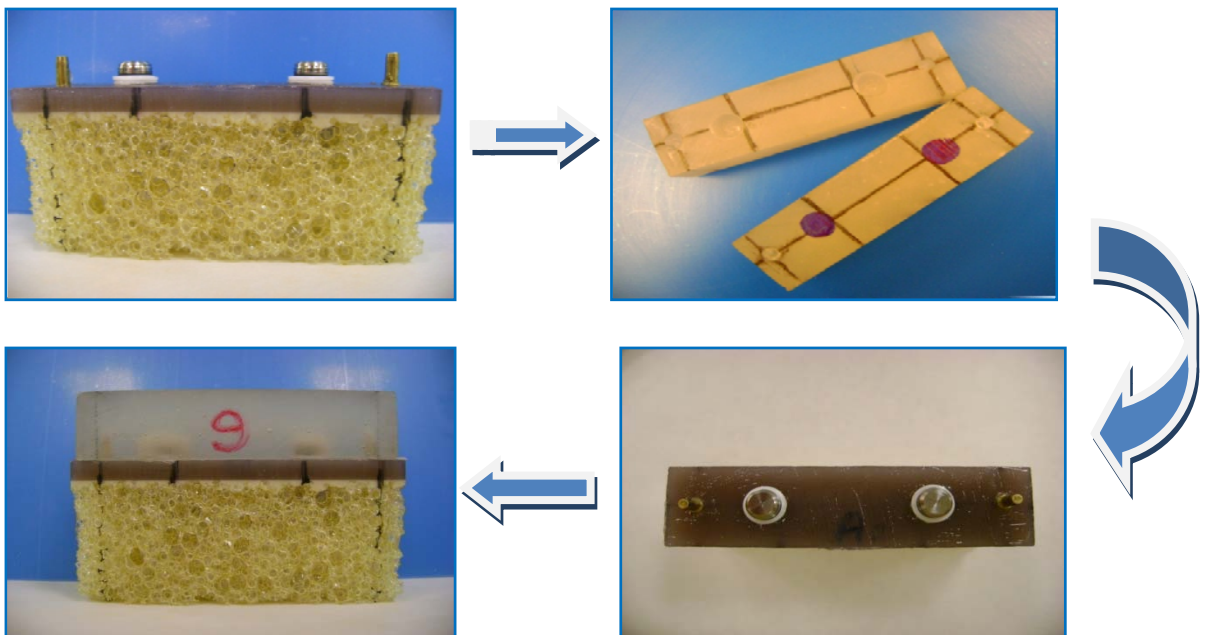


Figure 26: Placement of Locator® Male Components. A metal housing with black processing male was inserted into each abutment (1). Two holes were drilled in acrylic resin block in the exact location determined previously by drawing (2). Acrylic resin was mixed and poured into the holes. Afterward, the two blocks were aligned by using pins and allowed the resin to polymerize for 15 minute.

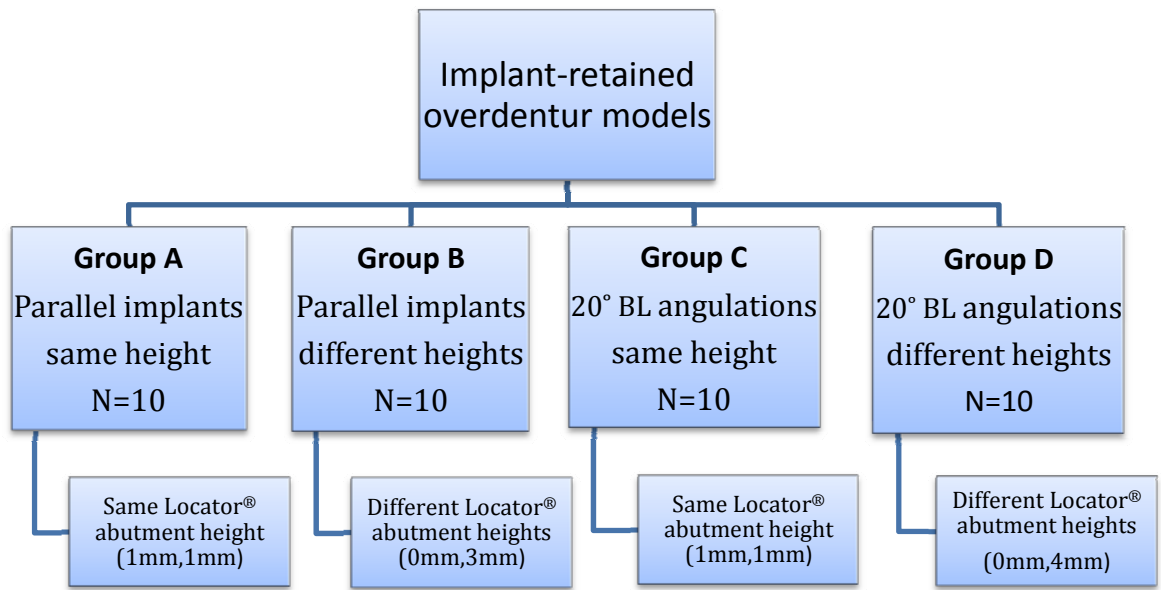


Figure 27: Classification of Groups.

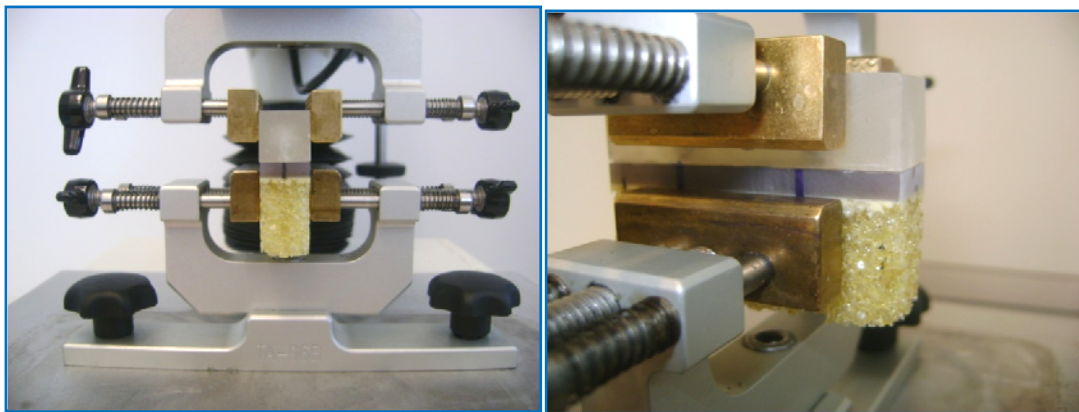


Figure 28: Assembly Placement. The assembly (Acrylic resin block attached to the bone block via Locator® attachments) was mounted to the grips of the texture analyzer.

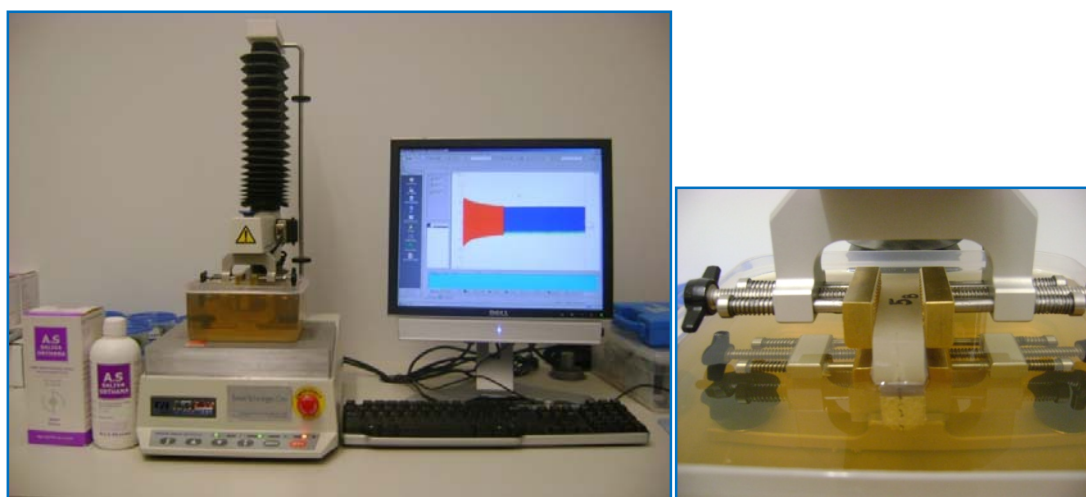


Figure 29: Cyclic Loading; Dislodging cyclic forces were applied to the overdenture attachment system using a texture analyzer.

Table 1: Demonstrates the number of cycles required for the retentive force to drop below 20 N of each sample.

Samples	Groups	Cycles required <20 N
1	A	5199
2	A	4467
3	A	4498
4	A	4381
5	A	6209
6	A	5838
7	A	5183
8	A	4918
9	A	5028
10	A	6728
11	B	5426
12	B	4970
13	B	5427
14	B	6362
15	B	5143
16	B	5729
17	B	4746

18	B	5619
19	B	5909
20	B	5224
21	C	4056
22	C	4854
23	C	4179
24	C	4834
25	C	3972
26	C	4775
27	C	4774
28	C	4664
29	C	4852
30	C	4217
31	D	3319
32	D	3293
33	D	3346
34	D	3715
35	D	3852
36	D	2227
37	D	2713
38	D	3807
39	D	3474
40	D	3682

Table 2: The mean and standard deviation of cycles required for the retentive force to drop below 20 N for each group.

Group	N	Initial Force Mean (Newton)	Mean of Cycles	Mean of Time	SD of Cycles	SD of Time
A	10	60	5244	3Y/7M/21D	785	6M/16D
B	10	65	5455	3Y/9M/13D	473	3M/28D
C	10	65	4517	3Y/1M/19D	364	3M/1D
D	10	68	3342	2Y/3M/25D	515	4M/8D

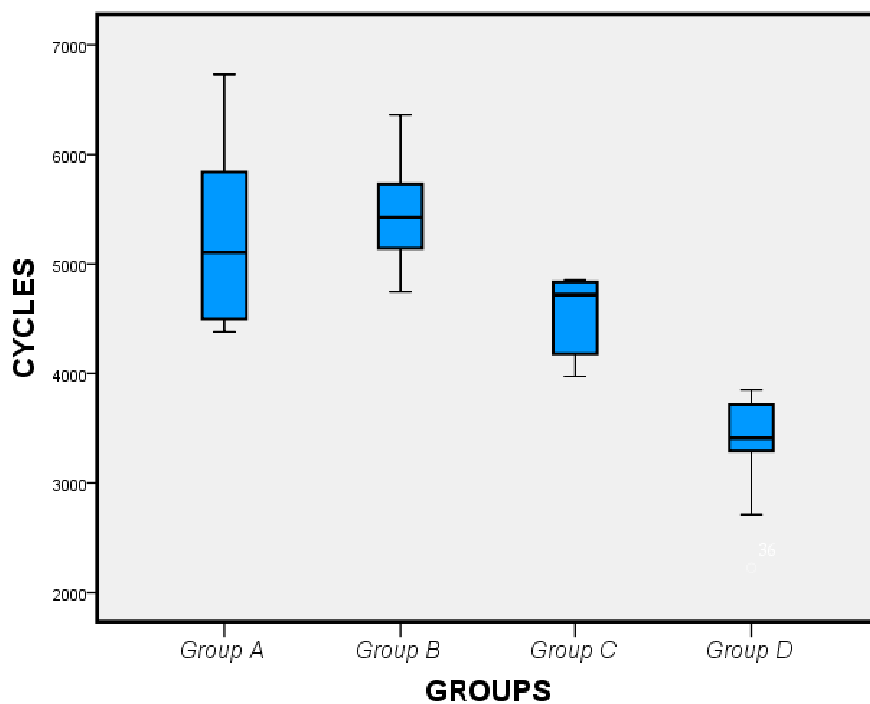


Figure 30: Box-plot showing the number of cycles required for each group for the retentive force to drop below 20 N.

Table 3: Two-way ANOVA results.

source	F	P-Level
Heights	7.502	.010
Angulations	65.067	<.001
Height*Angulations	15.487	<.001

Table 4: Mean and mean of time for groups with same height or angulations

Variables	Groups	Mean	Mean of Time
0° BL angulations	Groups A,B	5349	3Y/8M/17D
20°BL angulations	Groups C,D	3929	2Y/8M/22D
0mm difference	Groups A,C	4880	3Y/4M/20D
3mm difference	Groups B,D	4398	3Y/19D

Table 5: 2x2 table

	<i>Heights*</i>	
	0mm	3mm
<i>Angulations</i>		
0°	Group A	Group B
20°	Group C	Group D

*The implant were placed at same height (0mm height difference) or placed at different heights (3mm height difference).

Table 6: Independent samples t-test results.

Group Comparison	t	P-Level
Group A,B	-.726	.477
Group C,D	5.887	<.001
Group A,C	2.656	.016
Group B,D	9.543	<.001

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