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ABSTRACT

Title: The Effect Of Locator Abutment Height On The Retentive Values Of Pink Locator Attachments: An In Vitro Study

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Statement of problem: Based on alveolar bone height, morphology and implant position, overdenture attachments selected may not be at the same level vertically. Many studies have investigated the effect of implant angulation on the retention of Locator attachments, however, there are no studies to date that have investigated the effect of discrepancies vertically.

Purpose: The purpose of this study was to evaluate the effect of different heights of Locator abutments on the retention of overdentures.

Materials and methods: This study was conducted in vitro using four sets of edentulous mandible analogs with implants positioned at different depths (different vertical heights) relative to each other. There were 10 specimens in each of the four groups, with a total sample size of 40. Four groups of two implant-retained overdenture set-ups with Locator

attachments at different vertical levels of 0, 2, 4, 6 mm to each other were tested for changes in load-to-dislodgement using a universal testing machine after simulated chewing of six months. Data were analyzed using 1-way ANOVA and Tukey's Honestly Significant Difference Test (HSD). A $p \leq .05$ was considered significant.

Results: Varying heights of Locator abutments had a significant effect on the retentive values of the pink Locator attachments after six months of simulated chewing ($F = 7.342$, $p = .001$). The peak load-to-dislodgement ranged from 32.29 ± 8.77 N for Group 0 mm to 53.55 ± 10.20 N for Group 6 mm. When the difference in Locator abutment heights was 2 and 4 mm, the peak load was 37.10 ± 6.85 N and 41.94 ± 14.99 N respectively. The results of ANOVA and Tukey HSD showed that the retention of Group 0 mm and Group 2 mm was significantly lower than Group 6 mm. The retention of Group 4 mm was not significantly different from Groups 0 mm, 2 mm and 6 mm.

Conclusions: Within the limitations of this in vitro study, the following conclusions were drawn:

1. Retention of Group 6 mm was significantly higher than Group 0 mm and Group 2 mm. This is in contrast with the specific research hypothesis, which predicted that Group 0 mm would have the greatest retention. However, these differences were not clinically relevant.
2. Because a difference in Locator abutment heights between the two implants did not adversely affect retention, clinicians should choose Locator abutments according to the tissue thickness for implants at different levels.

The Effect of Locator Abutment Height on the Retentive Values of Locator Attachments:
An In Vitro Study

by
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TABLE OF CONTENTS

Introduction	1
Implant-Retained Overdentures	1
Implant Position and Overdentures	2
Retention of Overdenture.....	3
Guidelines for Selection of Locator Attachment	3
Retention of Locator Attachments	5
Biomechanical Forces of an Implant-Retained Overdenture	7
Purpose	8
Null Hypothesis	9
Specific Research Hypothesis	10
Materials and Methods	11
Fabrication of Mandibular Analogs	11
Impression of Mandibular Analogs	13
Investment of Occlusal Rims	14
Polymerization of Occlusal Rims	15
Fitting of Simulated Denture Bases	15
Testing Procedure	16
Statistical Analysis	20
Clinical Relevance Used for Power Analysis:	20
Power Analysis Results.....	20
Statistical Tests	21
Results	22
Discussion	27
Conclusion	31
References	32

LIST OF TABLES

Table 1 Experimental groups	11
Table 2 Mean, median and range of retention after the first pull.....	23
Table 3 One-way ANOVA comparing mean retention of the four groups after ten pulls	24
Table 4 Difference in retention (%) of the four groups after ten pulls.....	26

LIST OF FIGURES

Figure 1 Diagrams of mandibular analogs with Locator attachments of varying heights	12
Figure 2 Frontal and occlusal views of simulated denture base on the mandible analog	16
Figure 3 Denture base assembly for chewing simulation	17
Figure 4 Two assemblies of denture base on mandible analog subjected to simulated chewing using a chewing simulator.....	18
Figure 5 Application of tensile force using a universal testing machine.....	19
Figure 6 Mean peak load-to-dislodgement (N) for Locator abutments with varying heights after ten pulls.....	25

Introduction

Due to an aging population, complete edentulism is a condition that affects an increasing number of people annually. Although edentulism has been declining at a rate of about 1% per year in industrialized countries for the past 20 years, the decline is offset by the overall increase in size and age of the older population (Douglass *et al.*, 2002). According to the National Institute of Dental and Craniofacial Research epidemiological data, approximately 8% of the US adult population is completely edentulous (Beltran-Aguilar *et al.*, 2005).

Implant-Retained Overdentures

The McGill Consensus Statement on Overdentures asserted that mandibular 2-implant overdentures have been shown not only to be superior to conventional complete dentures, but also improve the quality of life of these patients regardless of the attachment system used (Feine *et al.*, 2002). This is because the implant overdenture prosthesis is significantly more stable, and more retentive, than the conventional denture prosthesis, enabling the patient to chew various foods more easily.

Indeed, a number of randomized-controlled clinical trials have demonstrated, in the mandible, increased patient satisfaction and reduced negative impact on quality of life with implant-retained overdentures as opposed to conventional dentures (Boerrigter *et al.*, 1995a; Boerrigter *et al.*, 1995b). Other studies reported an obvious improvement in chewing ability (Bakke *et al.*, 2002; Meijer *et al.*, 2003). It was also demonstrated, that there was a significant decrease in soreness, stomatitis, and ulceration in the anterior

mandibular tissues with the use of implant overdenture treatment when compared with conventional dentures (Johns *et al.*, 1992). Two dental implants are usually considered the minimum number necessary for mandibular implant overdenture treatment, allowing the mucosa and implants to help provide support, retention, and stability for the prosthesis (Zarb & Schmitt, 1996). It has been reported that there is no significant difference in peri-implant health, stress distribution in anterior mandibular bone, patient satisfaction and patient-perceived denture stability between two or four implant retained dentures (Zarb & Schmitt, 1990; Meijer *et al.*, 1994; Chao *et al.*, 1995; Wismeijer *et al.*, 1997; Batenburg *et al.*, 1998). Thus, fewer implants can be equally effective for the overdenture prosthesis and the two-implant overdenture is the treatment of choice because patients receive similar treatment benefit for less patient expense, treatment involvement and complexity.

Implant Position and Overdentures

It has been recommended that implants should be placed parallel to one another and to the path of insertion of the prosthesis (Preiskel, 1996). Clinically, these guidelines may be difficult to fulfill because of the anatomy and morphology of bone and the presence of vital anatomical structures (Preiskel, 1996; Banton & Henry, 1997). Excessively angulated implants, when used to retain overdentures, may present a restorative challenge particularly when free-standing attachment systems are used (Ortegon *et al.*, 2009). Concerns have been expressed that horizontal forces directed to angled implants may contribute to bone resorption (Brunski, 1988; Rangert *et al.*, 1989; Ichikawa *et al.*, 1996; Taylor, 1998) and expedited wear of attachments (Wiemeyer *et al.*, 2001; Gulizio *et al.*, 2005). 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 (Mericske-Stern, 1993). In some situations, implants are placed at different vertical heights due to limitations in anatomy of the alveolar bone. There are currently no guidelines regarding the position of the head of the implant, relative to the other implant, when used for overdenture treatment. In some clinical instances, abutments of different heights may compensate for the different levels of implant positions. One method of restoring implants for overdentures is with the use of attachments, with the Locator attachment being one of the most common on the market.

Retention of Overdenture

Retention of an overdenture is identified as the main characteristic influencing patient satisfaction (Naert *et al.*, 1991; Feine *et al.*, 1994). There is a wide variety of attachment systems available, namely: stud, magnet, and bar attachments which have proven to be clinically predictable and effective (Mericske-Stern, 1994). Some attachment systems utilize clips, for example: Hader clips (APM-Sterngold, Attleboro, MA), Dolder clips (Cendres+Métaux SA, Switzerland), and metal clips (APM-Sterngold). Other attachment systems are freestanding stud-type attachments such as: ERA (extracoronary resilient attachments, APM-Sterngold), ZAAG (Zest Anchors Inc, Escondido, CA), O-Ring, Locator (Zest Anchors Inc.), and magnets.

Guidelines for Selection of Locator Attachment

For selection of an implant Locator attachment, the tissue thickness is measured from the apical rim of the implant body to the crest of the gingiva. The corresponding abutment tissue cuff height that exactly equals the tissue measurement, or the next higher size available is then chosen. For Zest Anchors (Escondido, Calif.), Locator attachments have

tissue cuff heights ranging from 0 to 6 mm in 1 mm increments. There is no current protocol regarding selecting Locator attachments for implants at different heights.

Chung et al (Chung *et al.*, 2004) compared the retention characteristics of various attachment systems for implant overdentures. According to their study, attachment systems can be divided into 4 groups based on retention characteristics: high retention (ERA gray), medium retention (Locator LR white, Spheroflex ball, Hader bar & metal clip, ERA white), low retention (Locator LR pink) and very low retention (Shiner magnet, Maxi magnet, Magnedisc magnet).

Petropoulos et al (Petropoulos *et al.*, 1997) investigated the retention of various implant overdenture attachments. Nobel Biocare bar and clip was found to be significantly most retentive, followed by Sterngold ERA, Zest Anchor, Nobel Biocare Ball and lastly Zest magnet was significantly least retentive. Locator attachments were not tested in this study.

The number of implants and type of connector significantly affect the retention and stability of implant-supported overdentures. Sadig (Sadig, 2009) evaluated the retention and stability of implant-supported overdentures with respect to connector type and implant number and function. The retentive forces were measured during vertical and rotational dislodgement. Three types of connectors were used in the study; ball-type, Locators, and flat-type magnetic keepers. It was concluded that Locator attachments provide significantly higher retention and stability of implant-supported overdentures, followed by ball connectors and then magnets. According to Sadig (Sadig, 2009), the 2-implant design offered significantly less retention and stability than the 4-implant model.

Retention of Locator Attachments

There is extensive research that focuses on the retentive properties of Locator attachments. According to the manufacturer (Zest Anchors, Escondido, CA), the retention of clear inserts is standard (5.0 pounds), pink have light retention (3.0 pounds) and the blue have extra-light retention (1.5 pounds). Of the extended range nylon-inserts, the green inserts are listed as having standard retention (3.0-4.0 pounds), the orange have light retention (2.0 pounds) and red have extra-light retention (0.5-1.5 pounds).

Studies have shown that with normal function, Locator attachments are subject to a certain amount of loss of retention over time. Consequently, Locator nylon-inserts may require replacement multiple times over the lifetime of an overdenture. Al-Ghafli et al. (Al-Ghafli *et al.*, 2009) investigated the in vitro effect of different implant angulations and cyclic dislodgement on the retentive properties of an overdenture ball attachment system. It was determined that implant angulation had a significant negative effect on attachment retention longevity. Ball attachments with dislodging forces of <20 N on implants that are 0 to 5 degrees to each other maintained their retentive forces for five to six years whereas ball attachments on implants angulated at 20 degrees needed replacement after 1.8 years.

Evtimovska et al. (Evtimovska *et al.*, 2009) examined changes in retentive values of Locator abutments and Hader clips after 20 consecutive pulls and found that the retention of all attachments reduced significantly. Locators attachments on 20 degree angulated implants displayed significantly greater reduction in peak load-to-dislodgement compared to Locators on parallel implants and that the green extended range Locator attachments exhibited the greatest reduction. It was recommended that clinicians place and remove

the overdenture multiple times before delivery, especially for extended range Locator attachments. This would enable the clinician to accurately appraise the retention of the prosthesis.

Greenbaum (unpublished thesis) tested the retentive values of initially placed and replacement nylon-inserts for Locator attachments to determine if the decline in retentive values of Locator attachments was due to nylon-insert deterioration. It was found that there was no significant difference in the retentive values of the two. However, the replacement nylon-inserts lost retention at twice the rate of the initially placed nylon-inserts after two years of simulated overdenture function. Wear was observed on the titanium nitride coated Locator abutment, which was postulated to be the cause for the difference in measured rate of retention loss between the initial and replacement nylon-inserts.

Several studies have investigated the effect of cleansing solutions on the retention of various attachment systems. Nguyen et al. (Nguyen *et al.*, 2010) evaluated the changes in retention of pink Locator attachments after exposure to various denture cleansers. Pink Locator attachments were soaked for the equivalent of six months of clinical use in the following solutions: Water (control), Polident Regular, Efferdent, 6.15% sodium hypochlorite, Polident Overnight, and Cool Mint Listerine mouthwash. Peak load-to-dislodgement was recorded to reflect changes in the retention of the Locator attachments after soaking. Cool Mint Listerine mouthwash significantly increased the retentive values of the attachments. Efferdent caused a small, significant reduction, and NaOCl caused a large, significant reduction in the retentive values when compared to the control group. There was no significant difference in the retentive values of attachments soaked in

Polident Regular or Polident Overnight when compared to the control group. The authors concluded that soaking Locator attachments in NaOCl or Cool Mint Listerine is not recommended because of their effect on retentive values and on the color of the Locator attachments.

Biomechanical Forces of an Implant-Retained Overdenture

Assuncao et al. conducted a two-dimensional Finite Element Analysis to compare stress distribution induced by posterior functional loads on different attachment systems of implant-retained mandibular overdentures (Assuncao *et al.*, 2008). Unsplinted implants presented higher stress values in cortical bone compared to a bar attachment. Implant splinting through the bar attachment increased the stress distribution of applied loads across the implants. The ball attachment system showed higher stress in relation to the supporting tissues than the bar system. Splinted implants associated with the bar-clip system improved the transmission of occlusal loads. However, Locator attachments were not tested in this study. Also, no statistical analysis was done.

Based on alveolar bone height and morphology, implant placements for overdenture attachments may not be parallel in either the vertical or the horizontal axis. Many studies have investigated the effect of vertical angulation of implants on the retention of overdenture attachments (Gulizio *et al.*, 2005; Al-Ghafli *et al.*, 2009), however, there are no studies to date that have investigated the effect of discrepancies in the horizontal axis. Should the same protocol for choosing locator attachments be based on the soft tissue thickness, or should the Locator attachment height be used to compensate for the different vertical height of the implants?

Purpose

The purpose of this study was to evaluate the effect of different heights of Locator attachments on the retention of overdentures after six months of simulated chewing. This study explored whether Locator attachments with a 0 mm difference in height had similar retention compared to Locator attachments with a 2, 4 and 6 mm difference in height. It is expected that this project will help clinicians make an informed decision about selecting the height of Locator attachments in patients with varied implant levels. This will not only positively affect the retention of overdentures, but also the longevity of Locator attachments and nylon inserts. Other research on the retention of Locator attachments found that implant angulation had a significant negative effect on attachment retention and longevity. No research has been done to evaluate the effect of Locator abutment height on the retention of overdentures.

Null Hypothesis

After simulated chewing of 6 months, there is no significant difference in the peak load-to-dislodgement of Zest Locator abutments with a 0, 2, 4 or 6 mm difference in height.

Specific Research Hypothesis

After simulated chewing of 6 months, Locator abutments with a 0 mm difference in height will show significantly greater peak load-to-dislodgement values than the Locator abutments with a 2, 4 or 6 mm difference in height.

Materials and Methods

This study was conducted in vitro using four sets of edentulous mandible analogs with implants positioned at different heights relative to each other (Table 1, Figure 1).

Table 1 Experimental groups

Group	Difference in Locator attachment levels (mm)
0mm	0
2mm	2
4mm	4
6mm	6

Fabrication of Mandibular Analogs

An analog of an average-sized edentulous mandible with moderate resorption was fabricated using a cast-former (Model V50; Columbia Dentoform Corp, New York, NY). Autopolymerizing acrylic resin (Jet Acrylic; Lang Mfg Co, Wheeling, IL) was mixed and poured into the cast-former. After the acrylic resin polymerized, a coarse lab carbide rotary cutting instrument (#H79G; Brasseler, Savannah, GA) was used to prepare 2 holes in the area of the mandibular canines. Each hole was large enough to house an implant analog (Replace Select, trilobe internal hex, regular platform; Nobel Biocare, Yorba Linda, Calif). Using a dental surveyor (Ney Dental International; Bloomfield, Conn) and guide pins, 2 parallel implant analogs were placed in the prepared sites and fixed using autopolymerizing acrylic resin. The implant analogs were placed in the canine position, bilaterally, 22 mm apart, which is similar to the distance between two natural canines (Sinclair & Little, 1983). The difference in implant heights was simulated by using

Locator attachments of different heights: 0, 2, 4 and 6 mm to standardize and limit differences between the mandibular analogs (Figure 1).

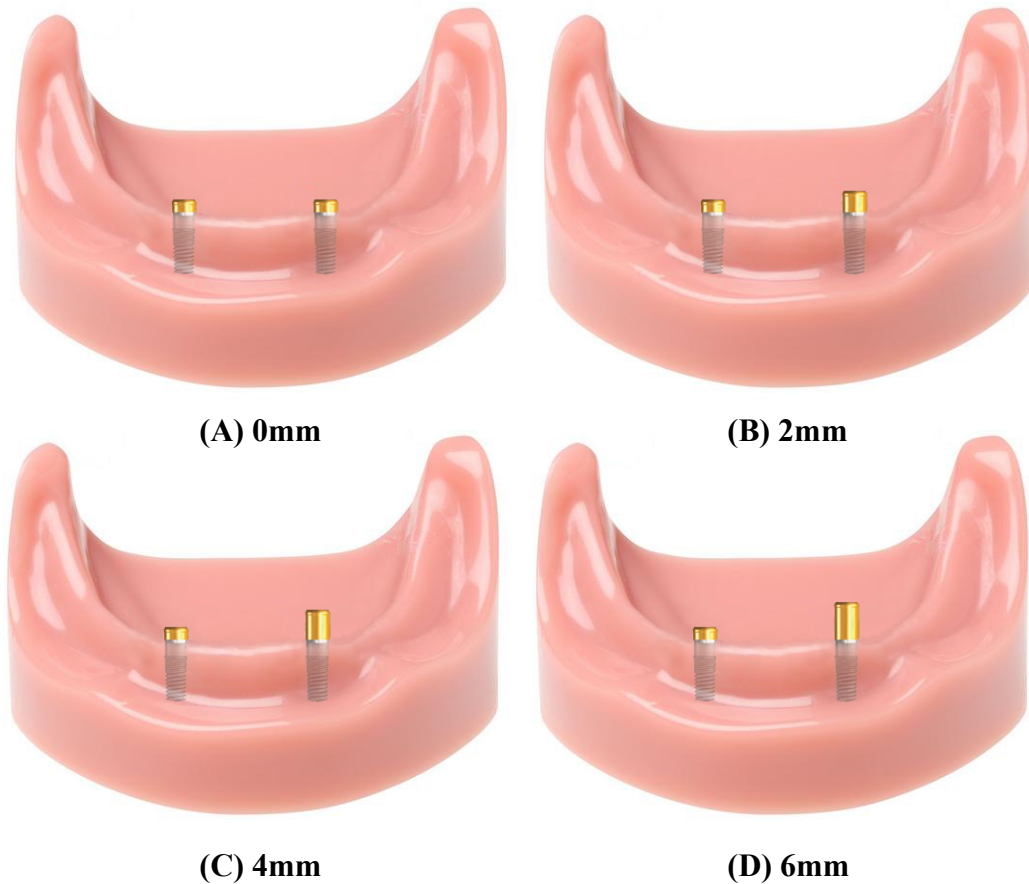


Figure 1 Diagrams of mandibular analogs with Locator attachments of varying heights.

(A) Locator attachment of 0 mm in height on both right and left.

(B) Locator attachment of 0 mm in height on right and 2 mm on left.

(C) Locator attachment of 0 mm in height on right and 4 mm on left.

(D) Locator attachment of 0 mm in height on right and 6 mm on left.

To simulate the resiliency of the mandibular soft tissues on the edentulous analog, 4 mm was removed from the surface of the oral analog using a carbide rotary cutting instrument

(#H77E; Brasseler USA) and replaced with rubber gingival material (Gingival Mask HP; Henry Schein Inc, Melville, NY) (Damghani *et al.*, 2012). To ensure that a uniform layer is removed, depth grooves were carved on the surface of the oral analog using a carbide rotary instrument (#H129E; Brasseler). Using the same bur, 3 escape grooves were carved on the sides of the oral analog to provide space for excess rubber gingival material to flow. After reduction, the surface of the model former was lightly lubricated with petroleum jelly (Swan; Perrigo, Allegan, Mich). A uniform layer of rubber gingival material was injected on the surface of the oral analog. The oral analog was seated back inside the model former while caution was exercised to make sure that the base of the analog was level with the surface of the model former. Excess gingival material covering the dental implant analogs was removed using #11 scalpel (Becton Dickinson, Franklin Lakes, NJ).

The matrices of the stud attachments (Locator attachments; Zest Anchors LLC, Escondido, Calif) were attached to the implants on the oral analog using the abutment driver part of the attaching tool (Locator Core Tool; Zest Anchors LLC), and torqued to 30 Ncm with a wrench (Locator Torque Wrench; Zest Anchors LLC) per the manufacturer's recommendation. The Locator attachments attached was 0 mm in height on the right implant and 0, 2, 4 and 6 mm in height on the left implant (Table 1, Figure 1).

Impression of Mandibular Analogs

Two layers of baseplate wax (TruWax; Dentsply, York, Pa) were placed on the oral analog and custom trays were fabricated (light polymerized custom tray material, Triad; Dentsply) and were polymerized for 4 minutes (Triad 2000 Visible Light curing Unit;

Dentsply) according to the manufacturer's recommendation. The custom trays were removed from the oral analog and the internal surface was polymerized again for 4 minutes. The custom trays were made 2 mm short of the vestibule. To ensure controlled pressure during impression making, they were extended in 3 spots to contact the acrylic resin of the vestibule of the oral analog. In order to provide a tripod effect, one stop was in the anterior and the other two in the area of the retromolar pads. The custom trays were lightly coated with vinyl polysiloxane (VPS) adhesive (Caulk tray Adhesive; Dentsply) and air-dried for 24 hours. The surface of the oral analog was lubricated with petroleum jelly (Swan; Perrigo) and final impressions of each specimen were made using light body VPS impression material (Aquasil Monophase; Dentsply). These impressions were boxed with boxing wax (Dentsply Boxing Wax; Dentsply) and poured in vacuum mixed Type III dental stone (Denstone Golden; Heraeus Kulzer, South Bend, Ind).

One layer of light polymerized denture base material (Triad pink unfibred denture base material; Dentsply) was adapted over each record base and light polymerized for four minutes. A wax rim (TruWax; Dentsply) was adapted and secured over the record base using wax (Sticky Wax; Kerr Corp, Romulus, Mich). The dimension of the wax rim was 34 x 8 x 8 mm. A putty (Coltene/Whaledent, Cuyahoga Falls, Ohio) index of this occlusal rim was made and used to fabricate similar occlusal rims for the remaining three denture bases. The dimensions of the rims corresponded to an average of the first and second premolars and molars.(Nelson & Ash)

Investment of Occlusal Rims

The record bases were placed on the casts and their borders were sealed with melted baseplate wax (TruWax; Dentsply). The casts were invested in the drag of the denture

processing flasks (Teledyne Hanau Processing Flask; Teledyne Hanau Inc, Buffalo, NY) using type II dental plaster (Modern Material Dental Plaster; Heraeus Kulzer). The undercuts in the investment were removed and the investment was allowed to set. A thin layer of separating medium (Modern Material Separating Medium; Heraeus Kulzer) was applied to the surface of the investment. The cope was positioned in place and a second mix of type II plaster was poured into the flask until the ring was filled completely and the top placed in position. The flasks were put into a boil-out tank (Nevin Laboratories, Chicago, Ill) for eight minutes to eliminate the wax. After separating the cope and drag, the remaining wax was rinsed with hot running water. A layer of separating medium (Modern Material Separating Medium; Heraeus Kulzer) was applied to the plaster of the investment in both portions and allowed to bench cool.

Polymerization of Occlusal Rims

Heat polymerized polymethylmethacrylate resin (Lucitone 199; Dentsply) was mixed according to the manufacturer's instructions and trial packed, at 1500 psi three times in the doughy stage (Nevin Pneumatic Press Unit; Nevin Laboratories) and at 3000 psi for one final pack. The flasks was clamped (Hanau Flask Compress; Teledyne Hanau) and polymerized at 165 degrees F (74 degrees C) for nine hours from the time of initial placement into the denture-curing unit (Nevin 4900 Electronic Denture Curing system; Nevin Laboratories). After allowing enough time for bench cooling, the two parts of the flask were separated. The denture bases were retrieved, finished, and polished.

Fitting of Simulated Denture Bases

The intaglio of the denture bases was painted with Pressure Indicating Paste (Mizzy Pressure Indicating Paste; Keystone Industries, Cherry Hill, NJ) and adjusted with a

carbide bur to ensure intimate contact of the ridge to the denture base (Figure 2). Relief holes, corresponding to each Locator attachment, were made on the denture bases using a #8 acrylic round rotary cutting instrument (Brasseler USA) to make sufficient room for the housing/patrix part of the attachment (Locator Attachment; Zest Anchors LLC). The Locator housings with black patrix processing attachments were placed on each Locator abutment and white spacers were placed around the matrix to prevent the autopolymerizing resin from locking in. Using autopolymerizing acrylic resin (Jet Acrylic; Lang Mfg Co), the patrices were picked up in the denture base. The black processing attachments were replaced by pink Locator attachments using a Locator Core Tool (Zest Anchors LLC). Pink Locator attachments were tested in this experiment as they are the most widely used by dentists (personal communication with the sales department of the manufacturer).

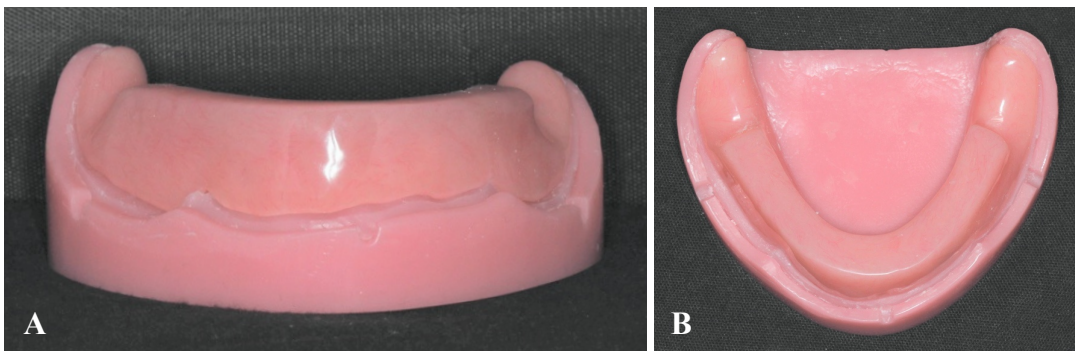


Figure 2 Frontal (A) and occlusal views (B) of simulated denture base on the mandible analog.

Testing Procedure

Each specimen involving the full assembly of the simulated denture base on the oral analog was subjected to a chewing simulator (CS 4.2, SD Mechatronic GmbH,

Feldkirchen-Westerham, Germany) to simulate intraoral conditions (Figure 4). Each specimen was subjected to a dynamic cyclic load with both vertical and lateral components (120,000 cycles, 5kg of weight, 3 mm height, 0.7 mm lateral movement, vertical and lateral speeds of 60 mm/s, frequency 1.6 hz) (Heintze, 2006). According to the literature, 120,000 cycles in a chewing simulator corresponds to 6 months of clinical service (DeLong *et al.*, 1985; Sakaguchi *et al.*, 1986). The load was applied to each specimen via a stylus contacting the center of a flat metal plate embedded on the occlusal surface of the denture bases (Figure 3).

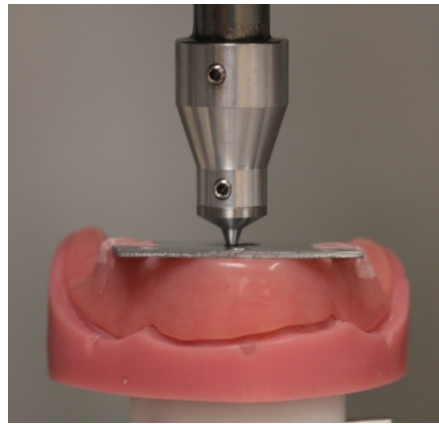


Figure 3 Denture base assembly for chewing simulation: Stylus contacting metal plate of denture base during chewing simulation

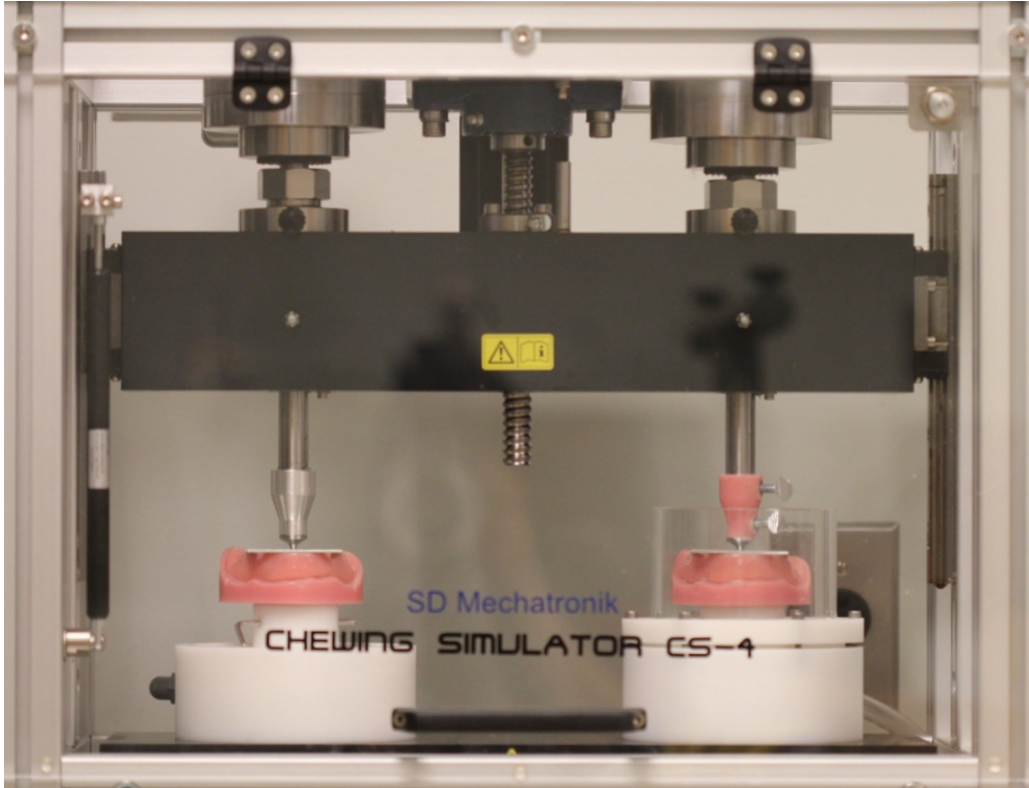


Figure 4 Two assemblies of denture base on mandible analog subjected to simulated chewing using a chewing simulator.

The specimens were tested for peak load-to-dislodgement on a universal testing machine (Satec Material Testing Equipment, T Series, Scottsdale, AZ) after simulated chewing (Figure 5). The Satec machine was used at a crosshead speed of 2 in/min (Breeding *et al.*, 1996; Varghese *et al.*, 2007). First, the denture bases were clamped down and stabilized to the lower member of the Satec machine. The denture base with the metal housing embedded in it was clamped to the upper part of the Satec Testing machine. A tensile force was applied to the testing specimen until the Locator attachment separated from the Locator abutment. After each separation of the denture bases, the measured peak load-to-dislodgement value was recorded. Each specimen was subjected to ten consecutive pulls (Williams *et al.*, 2001). The same procedure was repeated for each of the ten specimens

in the four groups. The mean of the ten pulls was determined for each specimen. The overall mean for each group was found by averaging the means of each specimen in that group. This mean retentive value was compared statistically across the four groups.



Figure 5 Application of tensile force using a universal testing machine.

Statistical Analysis

Clinical Relevance Used for Power Analysis:

To determine the relevance of the collected data, the different retention strengths offered by Zest Anchors for the different Locator nylon-inserts were considered. The dual-retention nylon-inserts, offered in three colors, correspond to three levels of retention. The clear “standard retention” nylon-inserts are reported to have 5 lbs (22.24 N) of retention. The pink “light retention” nylon-inserts are reported to have 3 lbs (13.34 N) of retention. The blue “extra light retention” nylon-inserts are reported to have 1.5 lbs (6.67N) of retention (Locator Implant Attachment System Product Brochure, Zest Anchors, Escondido, CA). Close examination of this information showed that blue nylon-inserts are designed to have fifty percent less retention than the pink nylon-inserts. Therefore, the point at which a Locator pink nylon-insert loses fifty percent of its retentive value is clinically important. At this point, the attachment system is no longer behaving as originally intended. In essence, the character of the behavior of the attachment system has changed from pink “light retention”, to blue “extra light retention”. This is clinically important because it is a detectable change.

Power Analysis Results

Using the clinical relevance of a 1.5 lb (6.67N), decrease of 50% in retention between the pink nylon-insert and the blue nylon-insert, the following power analysis was conducted. Using one-way ANOVA, with an n of 10 in each group, an effect size of .65, a one-tailed test, and a p value of $\leq .05$, power was equal to .92 for implant level. Therefore, an n of 10 in each group was used in this study.

Statistical Tests

Using the Levene test for homogeneity of variance, no significant difference was found between the variances in the four groups. Therefore ANOVA and Tukey's Honestly Significant Difference Test (HSD) were used to examine the results for significant differences in groups. Results are reported in Newtons (N) as mean (\bar{x}) and standard deviation (SD). A $p \leq .05$ was considered significant.

Results

In Group 0 mm, the peak load-to-dislodgement after the first pull ranged from 24.22 N to 53.84 N. In Group 2 mm, it was 29.03 N to 51.39 N. In Group 4 mm, 29.52 N to 91.00 N and lastly in Group 6 mm, the range was 37.46 N to 78.26 N (Table 2).

Varying height of Locator abutments had a significant effect on the retentive values of the pink Locator attachments after ten pulls following six months of simulated chewing ($F = 7.342$, $p = .001$, Table 3 and Figure 6). The peak load-to-dislodgement after ten pulls ranged from 32.29 ± 8.77 N (7.26 lb) for Group 0 mm to 53.55 ± 10.20 (12.04 lb) N for Group 6 mm. When the difference in Locator abutment heights was 2 and 4 mm, the peak load was 37.10 ± 6.85 N (8.34 lb) and 41.94 ± 14.99 N (9.43 lb) respectively. The results of ANOVA and Tukey's HSD showed that the retention of Group 6 mm was significantly higher than Group 0 mm ($p = .0005$) and 2 mm ($p = .007$). The retention of Group 4 mm was not significantly different from Groups 0mm ($p = .197$), 2mm ($p = .741$) and 6mm ($p = .087$).

Table 2 Mean, median and range of retention after the first pull

Groups	N	Mean (peak load, N)	Median (N)	Range
0 mm	10	36.62 ± 9.45	34.62	29.62
2 mm	10	40.97 ± 7.19	42.32	22.36
4 mm	10	49.53 ± 18.50	44.77	61.49
6 mm	10	60.12 ± 13.00	62.22	40.80

Table 3 One-way ANOVA comparing mean retention of the four groups after ten pulls

Groups	N	Mean (peak load, N)	SD	Range	F	p
0 mm	10	32.29 ^a	8.77	27.19	7.342	.001
2 mm	10	37.10 ^a	6.85	20.95		
4 mm	10	41.94 ^{a,b}	14.99	50.56		
6 mm	10	53.55 ^b	10.20	32.56		

Groups with the same letter are not significantly different ($p > .05$).

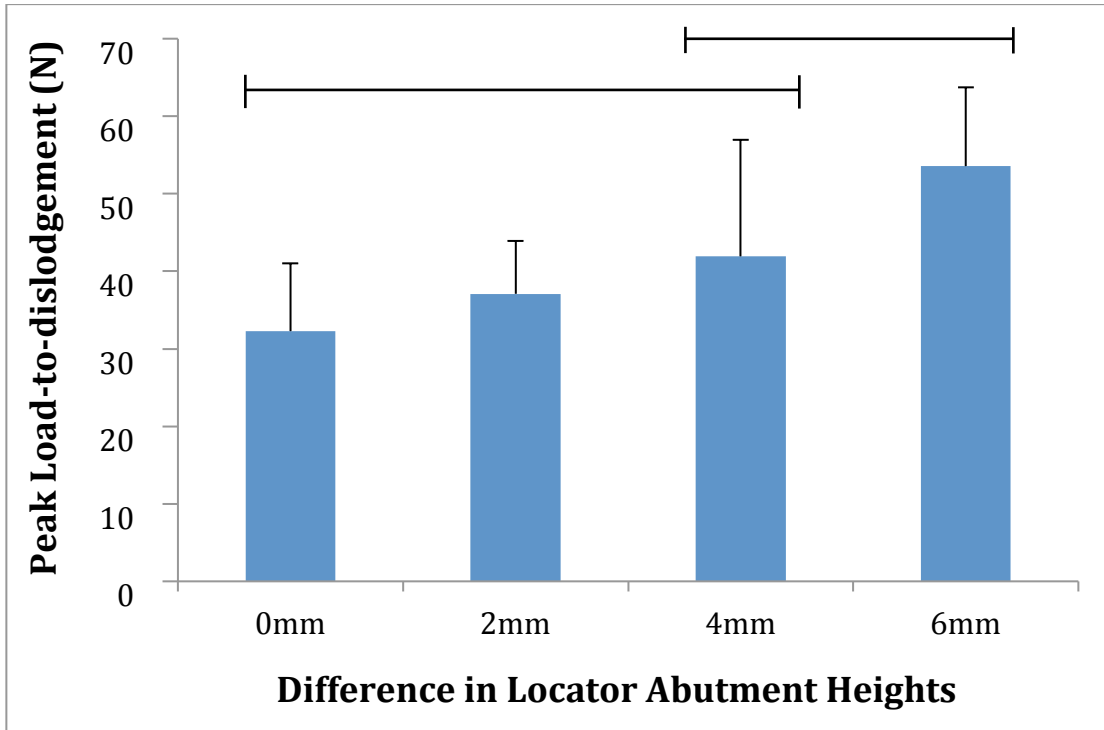


Figure 6 Mean peak load-to-dislodgement (N) for Locator abutments with varying heights after ten pulls ($F = 7.342$, $p < .001$). Groups under the same bar are not significantly different.

Table 4 Difference in retention (%) of the four groups after ten pulls

Groups	Groups	Difference in retention (%)
6 mm	4 mm	21.68
	2 mm	30.72
	0 mm	39.70
4 mm	2 mm	11.54
	0 mm	23.00
2 mm	0 mm	12.96

Discussion

This in vitro study investigated the effect of Locator abutment height on the retentive values of Locator attachments. The results of this study rejected the null hypothesis that after simulated chewing of 6 months, there was no significant difference in the peak load-to-dislodgement of Zest Locator attachments with a 0, 2, 4 or 6 mm differences in Locator abutment height relative to each other. Group 0 mm exhibited the lowest retentive value of 32.29 ± 8.77 N (7.26 lb), while the retention increased with increasing difference in heights of the Locator abutments. Group 6 mm, with a retentive value of 53.55 ± 10.20 N (12.04 lb), demonstrated significantly greater retention compared to Groups 0 mm and 2 mm. This represents a reduction of 16.45 N or 39.5% in retention from Group 6 mm to Group 0 mm (Table 4). However, this is less than a 50% reduction in retention and therefore may not be clinically detectable. Also, the retentive value of 32.29 N in Group 0 mm is in excess of 20 N, which according to the literature is the minimum force required to maintain a denture in position (Caldwell, 1962; Walmsley, 2002). Thus, although there is a statistically significant difference between Groups 0mm, 2mm and 6mm; this difference may not be clinically important since all the results exceeded 20 N.

The enhanced retention as the difference in Locator height increased may be due to increased friction or a rotational path of dislodgement or both. The tallest Locator abutment of 6 mm had the largest surface area in contact with the intaglio surface of the denture compared to the shorter Locator abutments of 0, 2 or 4 mm. Although this contact area was relieved during the pick up of the Locator housing, it may not have been

sufficiently relieved and thus acted as guide planes, adding to the measured value of peak load-to-dislodgement.

Also, it was observed during testing that separation of the two Locator attachments from the two abutments did not occur at the same time, but often one following the other. The Locator abutment with the shorter height was often dislodged first followed by the taller Locator abutment. The different levels of the two Locator abutments may have provided a rotational path of dislodgement, therefore requiring a higher cumulative level of tensile force. This increased tensile force could then be transferred to the implant and could result in unfavorable stresses on the implant and surrounding alveolar bone. Additional research is required to determine the amount of force transferred from the Locator abutment to the implant and surrounding alveolar bone during insertion and removal of implant-retained overdentures.

Ten pulls were performed because Evtimovska et al. showed that a significant loss of retention occurred after the first removal of the Locator attachments from the abutments (Evtimovska *et al.*, 2009). Furthermore, their study showed that each additional time the Locator attachment was removed from the abutment, an additional decrease in retention occurred until retention plateaued after the sixteenth pull. Williams et al. evaluated the retention of five implant maxillary overdenture designs and subjected each overdenture to five tests of ten consecutive pulls (Williams *et al.*, 2001). Based on the results of these two studies, ten pulls were used to take into consideration the decrease in retention across the four groups.

To reduce variability between nylon-inserts, all of the pink Locator attachments were from the same batch and were randomly assigned into groups. However, results showed

that there was still a wide range of retention between the samples after the first pull (Table 2). Although the Locator attachments were from the same manufacturer's batch, the retentive values from the first pull indicated that they were not exactly identical. To account for this variation, the results for each attachment were averaged over 10 pulls. By averaging the results of ten pulls, the variances in the four groups were found not to be significantly different according to the Levene test. Therefore, the mean of ten pulls for each specimen was appropriate to be used as the value analyzed statistically across the four groups.

A crosshead speed of 2 in/min was used because it is the average speed at which patients remove implant overdentures from their fixtures (Sarnat, 1983). However, patients may remove their dentures at different rates, which in turn may affect the retention (You *et al.*, 2011).

The attachments were tested under simulated function of 6 months. Testing for longer periods may be necessary, as it has been demonstrated that Locator attachments can last up to 1.8 years (Al-Ghafli *et al.*, 2009). In this study, 120,000 cycles were performed to simulate six months of chewing. To simulate 1.8 years of function, the chewing simulation would have to be increased to 432,000 cycles. With a longer period of chewing simulation, the retention of the Locator attachments across the four groups will decrease due to the expedited wear of the attachments and therefore the differences in retention between the four groups may be even more apparent.

A limitation of this study was the lack of simulation of oral cavity conditions. The Locator attachments were subjected to peak load-to-dislodgement after six months of simulated chewing. This is different from intraoral conditions where intervals of chewing

and removal of dentures are repeated multiple times a day. Regular intervals of simulated chewing and tensile forces over a six-month period may result in decreased retention of the Locator attachments compared to tensile forces subjected only after an uninterrupted six months of simulated chewing.

Chewing simulation was done with one axis of rotation, whereas masticatory forces exert multiple axes of rotation on a denture. Multiple axes of rotation may cause the Locator abutments to wear more quickly and result in accelerated retention loss and more apparent differences in retention across the four groups. Lastly, dentures function dynamically in the oral cavity, subjected to a complex and variable biomechanical environment. Additional research should involve thermal cycling, biologic fluid environment, a longer period of simulated chewing and the effects of fatigue on material properties.

Conclusion

The results of this study show that the retention of Locator attachments increased with increasing difference in height of Locator abutments after six months of simulated chewing. In patients with implants at different depths relative to the bone level or each other, selection of Locator abutments should be based on the tissue thickness. Implants at different levels do not necessarily need to be compensated for by Locator abutment height. Choosing the Locator abutment that most closely corresponds to the tissue cuff height allows for more restorative space for the overdenture. If the taller Locator abutments are used to level out implants at different levels, the restorative space for the overdenture will decrease.

Within the limitations of this in vitro study, the following can be concluded:

1. Retention of Group 6 mm was significantly higher than Group 0 mm and Group 2 mm. This is in contrast with the specific research hypothesis, which predicted that Group 0 mm would have the greatest retention. However, these differences were not clinically relevant.
2. Because a difference in Locator abutment heights between the two implants did not adversely affect retention, clinicians should choose Locator abutments according to the tissue thickness for implants at different levels.

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