The effect of number and distribution of unsplinted maxillary implants on the load transfer in implant-retained maxillary overdentures: An in vitro study

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Statement of problem. There is little information as to how the number and distribution of implants affect the amount of load transmitted to the palate in implant-retained maxillary overdentures.

Purpose. The purpose of this study was to evaluate the effect of the number and distribution of dental implants on the load transmitted to the palate.

Material and methods. Eight implant analogues were placed in a replica of an average sized edentulous maxilla corresponding to the position of canines, first and second premolars, and first molars. The anteroposterior distance between the centers of implants in each quadrant was 8 mm. Fifteen denture bases were fabricated to fit the edentulous maxilla analogue. The denture bases were attached to the oral analogue using 6 different configurations of attachments (6 groups): Either no Locator attachments were used (control group), or the 2 most anterior attachments were attached, or 4 implants were engaged with a distance of 8, 16, or 24 mm between the centers of implants on left and right side, and finally, when all 8 attachments were activated. A force-measuring sensor was used to measure the force transmitted to the palate when a static force of 245 N was applied on the occlusal rims of the denture bases. Data (Newtons) were analyzed using 1-way ANOVA and Tukey's HSD test (α=.05).

Results. The mean (SD) amount of force measured on the palate when the overdentures were supported by 4 Locator attachments; [49.84 (26.52) at 8 mm spacing], [24.42 (15.05) at 16 mm spacing], [35.66 (22.94) at 24 mm spacing] was significantly lower than when no attachments [90.98 (20.20), control], or when 2 Locator attachments were used [76.07 (27.63)] (P<.001). When the overdentures were supported by 8 Locator attachments, the force measured on the palate [20.67(16.06) N] was significantly lower than that for the control group (P<.001), overdentures supported by 2 Locator attachments (P<.001), and overdentures supported by 4 Locator attachments when the distance between the anterior and posterior implants was 8 mm (P=.006).

Conclusions. The distribution of implants had a significant effect on the force measured on the palate of the oral analogue in overdentures retained by Locator attachments. When the distance between the 4 implants was 16 or more mm, the load was not significantly lower than the 8 implant design, suggesting that the palate of a 4 implant-retained overdenture with a distance of 16 mm or more, does not contribute significantly to the load transfer to underlying hard palate in the in vitro analogue evaluated. (J Prosthet Dent 2012;107:358-365)

Clinical Implications

It can be concluded that under ideal in vitro testing conditions, 4 dental implants with an inter-implant distance of 16 mm or greater substantially reduces the force generated by the denture base on the hard palate.

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Endosseous implants have been used extensively in rehabilitation of edentulous patients.[1,2] Besides providing retention, dental implants assist in reducing the impact of tissue borne edentulous prosthesis. They slow the rate of residual ridge resorption,[1, 3] increase the masticatory efficiency,[4, 5] and improve the stability and retention of dentures.[3]

Implant-retained overdentures are supported, retained, and stabilized by both implants and mucosa; therefore they generally require fewer implants than fixed implant prostheses.[6] In the maxilla, 4 endosseous implants, anecdotally and based on survival rate studies, are considered the minimum number needed for overdenture treatment.[6,7] The palatal coverage and proper extension of the overdenture is necessary to transmit the loads to primary load bearing areas in the maxilla.[8] However, palatal coverage may cause diminished taste[9,10] or reduced salivary flow due to long term denture wearing.[11,12] In some patients it is not possible to make overdentures with complete palatal coverage due to severe gagging reflex, large palatal tori or personal preference.[13,14]

As more implants are used to retain an overdenture, the responsibility for providing support shifts from the mucosa to the implants and extended soft tissue coverage becomes less critical. It is yet to be determined if this shift in load distribution on the implants is advantageous or not. A systematic review of the available literature on maxillary implant-retained overdentures (IROD) showed that there are no specific guidelines for the number of implants necessary to support a maxillary IROD.[15] Some authors have reported clinical success as determined by survival of prostheses and implants in treating patients with a palate-less IROD with a minimum of 4 supporting implants,[16-19] while others recommended the use of palatal coverage when 4 or less implants are used.[6,14] It has also been reported that the design of 6 implants and a bar had the highest success rate,[7] while others reported long-term success in treating patients with 4-6 unsplinted implants and reduced palatal coverage.[20]

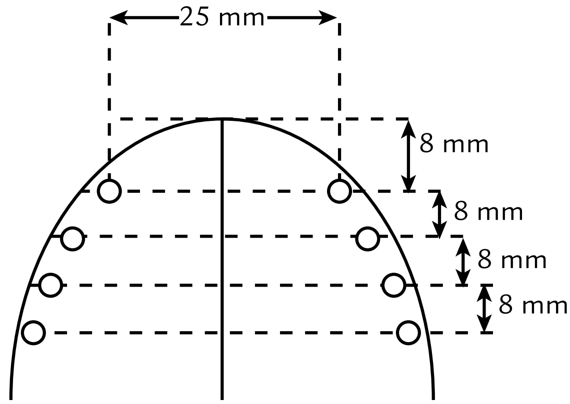
Despite different recommendations on the number of implants used in an IROD, other complicating factors in the maxilla can affect the decision making regarding the sufficient number of implants in a palate-less IROD. These factors include: the lower quality of bone in the maxilla, the muscles of mastication, the type of dentition of the opposing arch and resulting occlusal forces, the type and number of attachments, the interarch distance, the relationship between the shape of the residual ridge and form of the dental arch, and implant angulation.[6] These factors should be considered when deciding the number and distribution of implants in an IROD.

Most authors who examined the load transfer characteristics of maxillary IROD focused on the relationship between the type of the attachment used, and the load transfer to the implants.[14,21] Ochiai et al[14] used a photoelastic model to study 3 attachment system designs, including splinted and individual attachment designs, with and without palatal coverage.The authors found higher stress levels around the implants with a splinted design with and without palate, compared to the stud attachment designs. The authors also concluded that removal of the palatal support produced greater load transfer and more concentrated stress around the implants, and that incorporation of the palate might be more important than the attachment system used. Even though their study did not identify the exact position or anteroposterior distribution of the 4 implants used, but from the figures provided, it appears that the implants were placed in the areas of lateral incisors and first premolars. Benzing et al[22] demonstrated from a biomechanical perspective that a spread-out arrangement of 6 implants in the maxilla results in a better load distribution to the implants, than a concentrated arrangement. However, whether a less favorable load distribution will cause crestal bone resorption around the implants has neither been established nor rejected by any author.

To date, none of the published studies investigated the effect of implant number and distribution of the implants on the load transmitted to the palate. The present study was designed to measure the loads exerted on the hard palate. The research hypothesis was that there is a significant reduction in the amount of load transmitted to the palate in a 4-implant supported maxillary overdenture when the distance between the anterior and posterior implants increases from 8 to 16, to 24 mm.

MATERIAL AND METHODS

An analogue of an average-sized edentulous maxilla 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, Ill) 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 8 holes in the areas of maxillary canines, premolars and first molars. Each hole was large enough to house an implant analogue (Replace Select, trilobe internal hex, regular platform, 4.3 × 13 mm; Nobel Biocare, Yorba Linda, Calif). Using a dental surveyor (Ney Dental International; Bloomfield, Conn) and guide pins, 8 parallel implant analogues were placed in the prepared sites and were fixed using autopolymerizing acrylic resin. Analogues in the canine areas were 25 mm apart (distance from one canine to another) and 12 mm posterior to the most anterior part of the edentulous ridge (Fig. 1). The distance between the center of analogues inserted in the canine areas and analogues inserted in the first premolar



1 Distribution of implants in oral analogue.

areas was 8 mm, center to center. The same 8 mm distance was maintained between the centers of the remaining implant analogues on each side. The platform of all the implant analogues was placed 1 mm below the surface of the simulated maxillary ridge.

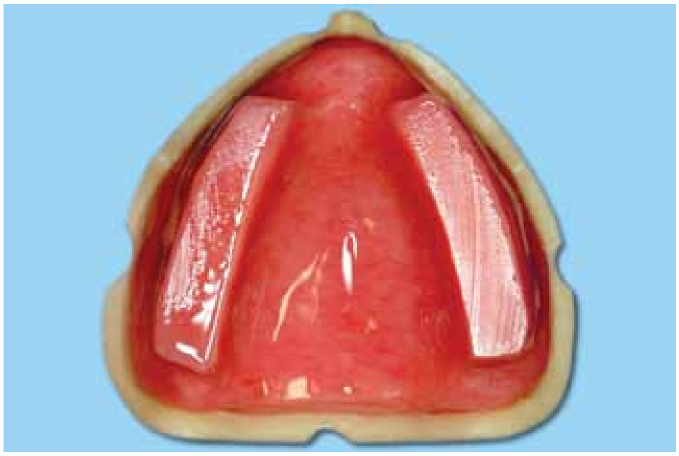
To imitate the resiliency of maxillary soft tissues on the edentulous analogue, a 4 mm thick layer from the surface of the oral analogue was removed using a carbide rotary cutting instrument (#H77E; Brasseler) and replaced with rubber gingival material (Gingival Mask HP; Henry Schein Inc, Melville, NY). To ensure that a 4 mm uniform layer was removed, depth grooves were carved on the surface of the oral analogue using a carbide rotary instrument (#H129E; Brasseler). Using the same bur, 3 escape grooves, 4 × 4 mm, were carved on the sides of the oral analogue 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 analogue. The oral analogue was seated back inside the model former while caution was exercised to make sure that the base of the analogue was level with the surface of the model former. Excess gingival material covering the dental implant analogues was removed using #11 scalpel (Becton Dickinson, Franklin Lakes, NJ).

According to studies,[23-27] the thickness of the palatal mucosa is variable depending on age, gender and location of the measurement on the palate. In general the mean reported thickness of the palatal masticatory mucosa in those studies, ranged between 2.4 ±0.7 to 5.11 ±1.07 mm. The thickness of simulated mucosa (4 mm) in this study is within the range reported in human literature and has been used previously in in vitro studies performed on oral analogues.[28,29]

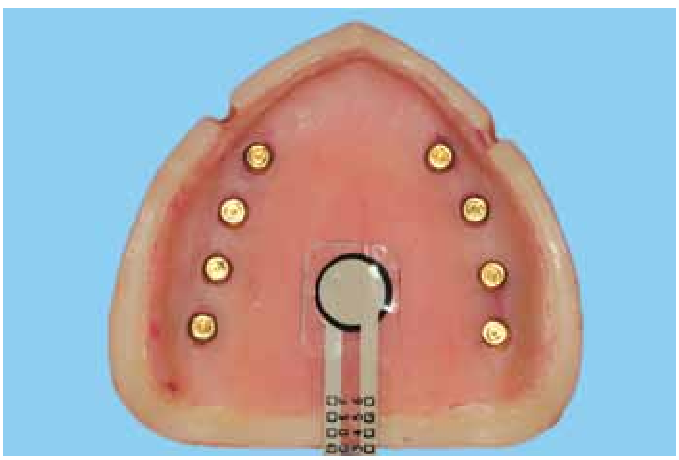
The matrices of the stud attachments (Locator attachments; Zest Anchors LLC, Escondido, Calif) were attached to the implants on the oral analogue using the abutment driver part of the attaching tool (Locator Core Tool; Zest Anchors LLC), and were torqued to 30 N/cm with a wrench (Locator Torque Wrench; Zest Anchors LLC) per manufacturer's recommendations. Two layers of baseplate wax (TruWax; Dentsply, York, Pa) were placed on the oral analogue and 15 custom trays were fabricated (light polymerized custom tray material, Triad; Dentsply), and polymerized for 4 minutes (Triad 2000 Visible Light curing Unit; Dentsply) according to manufacturer's recommendations. The custom trays were removed from the oral analogue and the internal surface was polymerized again for 4 minutes. The custom trays were made 2 mm short of the vestibule, but to ensure a controlled pressure during impression making, they were extended in 3 spots (stops) to contact the acrylic resin of the vestibule of the oral analogue. The positions of the stops were: 1 in the anterior and the other 2 in the areas of the hamular notches to provide a tripod effect. The custom trays were lightly coated with vinyl polysiloxane (VPS) adhesive (Caulk tray Adhesive; Dentsply) and let to air-dry for 24 hours. The surface of the oral analogue was lubricated with petroleum jelly (Swan; Perrigo) and 15 final impressions 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 unfibered denture base material; Dentsply) was adapted over each record base and light polymerized for 4 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 × 8 × 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 14 denture bases. The dimensions of the rims corresponded to an average sum of first and second premolars and molars.[30]

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



2 Final denture base with occlusal rims.



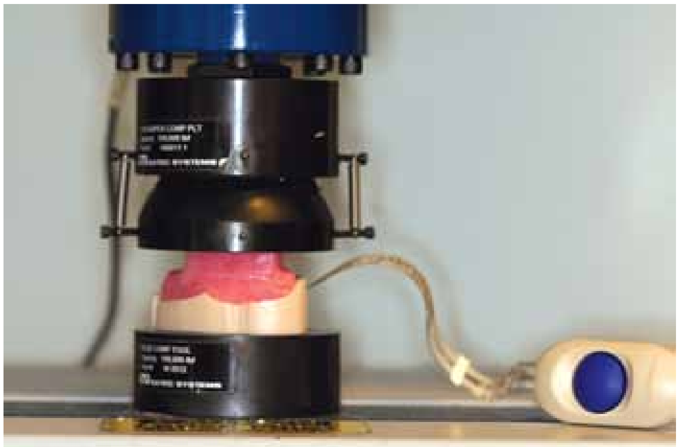
3 Force measuring sensor location on palate.

positioned in place and a second mix of type II plaster was poured into the flask until the ring was filled completely and the top placed in position. The flasks were placed in a boil-out tank for 8 minutes (Nevin Laboratories, Chicago, Ill) to eliminate the wax. The remaining wax was rinsed with hot running water after separating the cope and drag. A layer of separating medium (Modern Material Separating Medium; Heraeus Kulzer) was applied to the plaster of the investment in both portions and allowed to bench cool.

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

The intaglio of the denture bases were painted with pressure indicating paste (Mizzy Pressure Indicating Paste; Keystone Industries, Cherry Hill, NJ) and adjusted with carbide bur to insure intimate contact of the palate and the ridge to the denture base. Relief holes corresponding to each Locator attachment were made on 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 bases. The black processing attachments were replaced by extra-light blue patrix (without center stalks) attachments using a tool (Locator Core Tool; Zest Anchors LLC).

The Locator abutments were removed from the oral analogue and a force-measuring sensor (Flexiforce; Tekscan, South Boston, Mass) was placed in the middle of the palatal area of the original maxillary analogue. The sensor is 14 mm in diameter with a thickness of 0.127 mm. The active sensing area of the sensor has a diameter of 10 mm. The sensor was calibrated using known weights and then secured to the oral analogue by applying a small amount of adhesive (Zip Dry Paper Glue; Beacon Adhesive Company, Mt Vernon, NY) to the shaft area of the sensor. Caution was exercised not to apply adhesive to the sensor area. The outline of the sensor was marked with a marker on the maxillary analogue to mark the exact location in case the sensor moved (Fig. 3). Denture bases were seated over the maxillary analogue. A perpendicular static load of 245 N was applied bilaterally, to the occlusal rims of the denture bases, using a universal testing machine (Satec Universal Testing Instrument, T 5000 Series; Instron, Norwood, Mass) for 60 seconds to ensure that the applied force reached a stable continuous level that can be recorded accurately. The oral analogue and overlying denture base were carefully positioned in the center of the platform of the testing machine so that the upper member of the universal testing machine contacted



4 Application of force using universal testing machine.

TABLE I. Experimental groups

Group	Locator Position and Distribution
0	No Locators (control group)
2	Two Locators, canine area
4-8	4 Locators with 8 mm anteroposterior distance
4-16	4 Locators with 16 mm anteroposterior distance
4-24	4 Locators with 24 mm anteroposterior distance
8	8 Locators

both sides of the denture base simultaneously (Fig. 4).

Previous in vitro investigations applying load on maxillary overdentures, have used a static force of 100-110 N to simulate occlusal force.[14,31,32] In these studies the amount of occlusal force applied was determined arbitrarily. The maximum occlusal force in patients with overdentures has been shown to range between 120-375 N.[33,34] In this study, the force used (245 N) was well within these values.

The peak force measured on the palate was recorded. Data from the force-measuring sensor were collected using a laptop computer and software (ELF Flexiforce; Tekscan). In this study, a control group that used no attachments and 5 other groups with various locations and distributions of Locator attachments were used (Table I). Three of these designs were the experimental groups to study the force transmitted to the palate with different distributions of 4 Locator attachments. The other 3 designs were used to compare the experimental conditions to designs with 0, 2 and 8 Locator attachments.

Each denture base was tested with all 6 variations described in Table I. The order of the tests was randomly assigned using computer software (Excel 2007; Microsoft, Redmond, Wash). The force transmitted to the palate was recorded for all experimental groups and statistical analysis was completed using a 1-way analysis of variance (ANOVA) and Tukey's Honestly Significant Difference Test (HSD) for multiple comparisons (α=.05). Results are reported in Newtons as mean and standard deviation ranges (SD).

RESULTS

The results of the testing are reported in Table II. Load transmitted to the palate ranged from 20.67 (16.06) N for overdentures supported by 8 Locators to 90.98 (20.20) N for the control group (when no Locators were used). When 4 Locators were used with different distances between them, the force ranged from 49.84 (26.52) N to 24.42 (15.05) N. When 0 and 2 attachments were used the force on the palate was 90.98 (20.20) N and 76.07 (27.63) N respectively.

The results of ANOVA and Tukey HSD showed that the force measured on the palate in the 0 Locator and in IROD supported by 2 Locator attachments, was significantly higher than all other groups (Table II). The amount of force measured on the palate when the overdentures were supported by 4 Locator attachments was significantly lower than when none or 2 Locator attachments were used (P<.02). There was a significant difference between the force in the group supported by 4 implants with 8 mm and 16 mm distances (P=.03). However, the force in the groups with 16 mm distance and 24 mm distance were not significantly different (Table II). When the overdentures were supported by 8 Locator attachments, the load transmitted to the palate was significantly lower than that of the control group (P<.001), overdentures supported by 2 Locator attachments (P<.001) and overdentures supported by 4 Locator attachments when the distance between the anterior and posterior implants was 8 mm (P=.006). Table III details the mean percentage of force measured on the palate for each experimental group. The percentage values were obtained by dividing the recorded force values by 245 N (total force applied). Two examples of the force recorded under the dentures from each group are presented in Figure 5 and Figure 6. These figures demonstrate the amount of force measured on the palate from the moment of application of the static compressive force, to the moment when the force applied reached a maximum of 245 N and held for 60 seconds. The highest point of each line in the graph represents the peak force (N) measured on the palate.

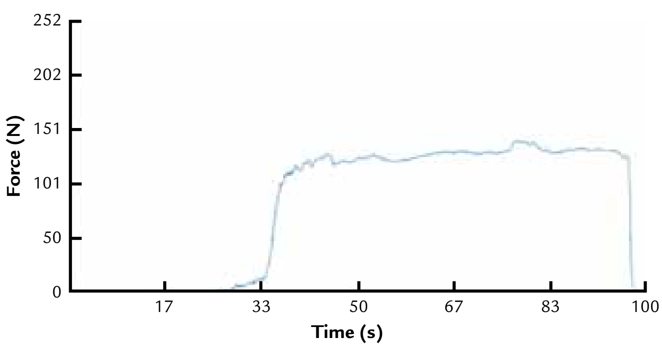
Table II. One-way ANOVA results and mean force values

Groups	N	Mean (N)	SD	F	*P*
0	13	90.98[a]	20.20	23.50	<.001
2	15	76.07[a]	27.63		
4-8	15	49.84[b]	26.52		
4-24	15	35.66b[c]	22.94		
4-16	14	24.42[c]	15.05		
8	15	20.67[c]	16.06		

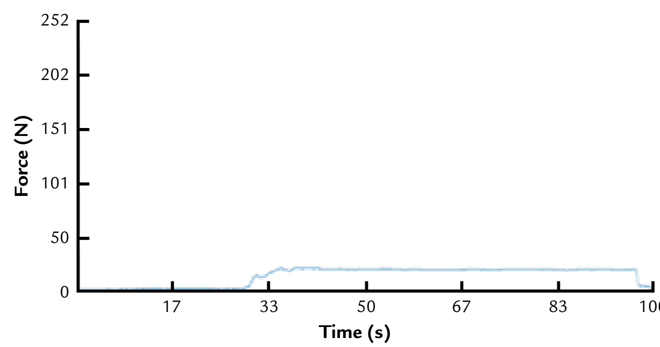
Means with the same lower case letter are not statistically significant (*P*>.05)

Table III. Percentage of total force transmitted to palate

Group	Percentage of Pressure
0	37%
2	31%
4-8	20%
4-24	15%
4-16	10%
8	8%



5 Example of force measurement on palate without attachements.



6 Example of force measurement on the palate with 8 attachments.

DISCUSSION

The results of this study support the research hypothesis; there was a significant difference in the amount of load transmitted to the palate in a 4-implant-supported overdenture, when the linear distance between the anterior and posterior implants increases from 8 to 16, to 24 mm. The distance between, and distribution of implants had significant effects on the load transmitted to the palate in an overdenture supported by 4 Locators.

The hard palate in a maxillary denture is the primary supporting area and it is generally used to provide support for dentures.[35] The results of this in vitro study suggest that when 4 or more implants are used, the support for the overdenture is primarily provided by the implants rather than the palate. This conclusion is based on the assumption that force measured on the palate is transferred solely to the supporting tissues and that remaining forces are transmitted to the implants. However, the load transmitted to the implants remains to be determined and should be measured directly.

When no Locators were used (control group), approximately 37% (89.66 N out of 245 N applied) of the load was transmitted to the palate. When only 2 implants were used, the amount of load on the palate, slightly declined, but this reduction was not significant (approximately 31%). These results indicate that even though 2 implants may provide a maxillary implant-retained overdenture with acceptable retention, the hard palate contributes considerably to the support of the overdenture.

When 4 locators, with minimum distance in between (8 mm), were used, the load transmitted to the palate significantly dropped from 37% with no Locators to 20%, demonstrating that support for the 4-implant retained overdenture is provided primarily by the implants and to a lesser degree by the palate. Nonetheless, as these results were significantly lower than when 4 Locators with 16 mm distance were used, these findings indicate that a palatal coverage may still be desirable when 4 implants with a distance of 8 mm or less are used. When the distance between the 4 implants increased to 16 and 24 mm, the mean load transmitted to the palate, significantly declined to 10 and 15% respectively. Although the force transmitted to the palate in when the distance between the Locators was 24 mm distance was higher than when the distance was 16 mm, the difference was not statistically significant.

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

Based on finite element analysis, photoelastic studies, and empirical experience, it has been recommended that at least 6 implants should be used if a palateless denture is to be fabricated.[6,7,17] In general, it is a common assumption, albeit not supported by strong evidence, that when using 6 or more implants the support for the complete maxillary overdenture is provided by the implants. This in vitro investigation is a first step in exploring the feasibility of eliminating the palate when only 4 independent non-splinted implants are used.

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

In the present study denture bases were adjusted before the study to insure initial positive seat and contact with the hard palate of the oral analogue. However, the resiliency of the vinyl polysiloxane soft tissue mimicking material used may not accurately replicate the resiliency of oral mucosa. In addition, the experiment was conducted on a moderate size maxillary analogue (45 mm anteroposterior length), and the results on a larger or smaller maxillary analogue could be different. Further, the implant analogues were placed parallel to each other and the effect of changing implant angulation was not tested.

It has been demonstrated that using a splinted implant design might have a negative impact on the stress concentration on the implants and the crestal bone.[14] Whether or not a splinted design of implants has an effect on the results of this study was not evaluated here. Other methods of studying the load transfer, such as incorporation of stress gauges around the implants, or photoelastic models, can render a clearer view of the load distribution pattern. These caveats notwithstanding, the results of this in vitro study demonstrate that the number and distribution of implants affect the forces measured on the palatal area of an average sized edentulous oral analogue.

CONCLUSION

Within the limitations of this in vitro study, using 4 Locator attachments produced significantly less force on the palate, compared to when zero or 2 Locators were used. There was a significant reduction in the force measured when the distance between the 4 Locator attachments increased from 8 to 16 mm. The use of 8 Locators produced the least amount of force on the palate, but this was not significantly different than the situations where 4 Locators with a distance of 16 or 24 mm were used.

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