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STRESS DISTRIPUTION OF IMPLANT RETAINED OBTURATORS USING TWO IMPLANT PLACEMENT CONFIGURATIONS FOR MAXILLECTOMY CASES: IN-VITRO STUDY

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ABSTRACT

INTRODUCTION: Implant-retained obturators have several advantages over traditional obturators for maxillectomy patients. Appropriate prosthetic design for specific condition after maxillary resection is essential for improvement of retention, stability of implant retained obturator.

OBJECTIVES: evaluation of peri-implant stress distribution of obturators retained by three implants placed with two different placement configurations.

MATERIAL AND METHODS: Three implants arranged in linear configuration and other three implants arranged in nonlinear configuration were inserted into two identical epoxy resin maxillary models of completely edentulous unilateral maxillary defect (Brown's class IIA). Two equal sets of twenty-six obturators were constructed; each with different implant placement configuration. Group I include thirteen obturators retained by three implants with linear configuration while Group II include thirteen obturators retained by three implants with nonlinear configuration. Both groups included the same attachment design (non-splinted Ball attachment). Using strain gauges, the two groups' differences in strain distribution were measured and compared. Using the universal testing machine, bilateral applications of vertical load and oblique load (30º and 45º) of 50 and 100 N were applied in order to assess stress distribution around implants.

RESULTS: There was statistically significant difference in strain value between group I (linear configuration) and group II (nonlinear configuration) after application of 30º oblique loading at 50 N and 100 N with p value < 0.0001 as group II exhibited lower strain values.

CONCLUSIONS: Implant placed with nonlinear configuration showed less strain values than implant placed with linear configuration.

KEYWORDS: Implant-retained obturator, Implant configuration, Ball and socket, Maxillectomy, strain gauges.

RUNNING TITLE: Implant configuration effect on stress distribution of implant-retained obturators.

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INTRODUCTION

Depending on the patient's condition, the ideal treatment plan may not always be possible to be administered. One of the factors that may hinder a specialist from providing the best prosthetic treatment is the remaining bone. Following surgical resection, the consistency, volume, and position of the remaining bone affect where implants are placed in the edentulous bone (1).

There is little research on implant-retained obturators in edentulous patients who have had maxillectomy. Clinical evidence, however, strongly justifies the use of dental implants to improve the prosthesis' stability, support, and retention in these patients (2).

Long-term stability in implant therapy is provided by maintaining osseointegration between the bone and implants through bone remodeling, which necessitates that the various stresses produced around the bone by the occlusal load delivered to the implant be within an appropriate range. (3). Furthermore, it has been observed that overloading, through concentrating stress at the implant-bone contact, can increase bone resorption (4).

However, there is a lack of standard data regarding the number, distribution, length, and diameter of implants in the residual tissues following resection of the defect in maxillectomy patients. Depending on the extent of the defect, the height of the residual alveolar ridge, and the amount and shape of the remaining palatal shelf, these parameters may be identified. According to Roumanas et al (5), for implant-retained obturators, four implants have been proposed.

Resected sites, radioactively treated tissues, and insufficient bone volume can all interfere with antero-posterior distribution, cross-arch stabilization patterns, and ideal implant placement (6).

Depending on where the implant is placed and how it is being loaded, different levels of stress are created in the implant. The occlusal load distribution was reported to be influenced by the implant's location (7).

A significant amount of bone in both the vertical and horizontal dimensions is a need for the placement of a dental implant, and when there is insufficient bone implant placement is difficult (1). The remaining alveolar crest should be suitable for implant placement in order to provide the greatest comfort for the obturator after maxillectomy (8).

In terms of biomechanics, the posterior portions of an edentulous maxilla where the main functional occlusal stress occurs during chewing are an ideal location for endosseous implants However, maxillary sinus pneumatization and inadequate bone volume in the posterior maxilla may prevent implant insertion (9).

According to Roumanas et al (5), implants implanted inside surgical defects have a low chance of surviving and are challenging to recover and maintain.

For the majority of patients who have had a maxillectomy, the residual premaxillary segment is regarded as the best area to place an implant since the anterior maxillary segment is located across from the area of the defect that is the most persistent along the posterior lateral wall. Furthermore, the premaxilla in most individuals may have sufficient bone volume and density, thus every attempt is made to maintain this bone segment as much as feasible (10).

The term "offset placement" describes an implant insertion technique where one implant is moved rather than three implants positioned in a straight line. In implant retained maxillary obturators, the direction of the load has a significant impact in the pattern of stress distribution (11). However, some studies indicated that when an offset implant is subjected to oblique loading, there may be a slight improvement in the distribution of bone stress, there was disagreement over the benefits of employing an offset design implant as opposed to those with a straight-line configuration (12).

Regarding the anchoring mechanism, stud attachments, O-rings, and ball attachments provide the optimum retention and stability for implant overdenture prostheses. Ball attachments are some of the most popular stud attachments due to their simplicity, affordability, ease of usage, and minimal chair side time requirements (13).

Further research is necessary since the literature lacks conclusive data about the number and configuration of implants necessary for the success of implant retained obturators. This is due to the poor circumstances in patients who have had maxillofacial surgeries for having the appropriate number and configuration of implants. This prompted us to contrast the use of two distinct implant placement configurations to retain the maxillary obturator in maxillectomy cases.

This study's null hypothesis was that there would be no significant difference in stress distribution between obturator retained by three implants arranged in linear configuration and obturator retained by three implants arranged in nonlinear configuration.

MATERIALS AND METHODS

This in vitro laboratory study was conducted to asses stress distribution at peri-implant area of implant-retained obturators using two different implant placement configurations which was compared to each other. Sample size was calculated to be 26 specimens allocated equally in the two study groups (14) Group I included 13 obturator specimens fabricated and retained by linear implant configuration (canine, premolar and molar areas). Group II included 13 obturator specimens retained by nonlinear configuration (central, premolar and molar areas).

Intervention (procedures)

Duplication of stone models

Two identical standard epoxy resin completely edentulous maxillary study models having class IIA maxillectomy arch according to Brown's classification (Fig1A) (15), with mucosa stimulating material, made of flexible polyurethane of 1.5 mm thickness (Ramses medical products factory, Alexandria, Egypt) were used in which the study models were duplicated into twenty-six maxillary stone cast (thirteen for each group) (Fig1B). These casts were opposed with a fully dentate Typodont Standard Teeth mandibular model (Fig1C). and were used for fabrication of closed hollow-bulb overdenture obturators.

Fabrication of the overdenture obturators (16, 17)

Trial obturator base with wax occlusion rim was constructed on one set of the duplicated stone models which opposed with fully dentate Typodont Standard Teeth mandibular model and were mounted on mean value articulator. Maxillary acrylic teeth were arranged and carefully adjusted. Twenty-six duplicated maxillary stone models were used to build 26 trial obturator bases.

To achieve standardization of all trial obturators, the opposite completely dentate Typodont Standard Teeth mandibular model with the same mounting was used to arrange the same size maxillary acrylic teeth (Acrostone cross-linked acrylic teeth, Cairo, Egypt) on all the trial obturator bases.

The obturator part was made following Elshimy's (16) modifications to the conventional closed hollow-bulb technique as in the following procedures:
Two layers of base plate wax were applied to each cast, fitting to the defect walls up to the palate edges (Fig. 1-D), then flasked and rinsed away to create space for the obturator part. Heat polymerized acrylic resin (Acrostone heatcure material, Cairo, Egypt) was loaded into the area and processed in accordance with the manufacturer's instructions (Fig 1-E).

Lateral defect walls were sectioned to assist in retrieving the obturator part without harming the cast after cautious deflasking to preserve the cast. Without covering the margins of the obturator part, the internal space of the obturator part was filled with a lump of soft plaster and shaped to adopt the shape of the normal palatal contour (Fig. 1-F).

The cover for the obturator part was then created using two layers of base plate wax. To make space for the cover component, the waxed portion was flasked and cleaned out. A moist cellophane paper was adapted to the obturator part's edges (Fig 1-G). Heatcured acrylic resin was packed into the space then cured in accordance with the manufacturer's specifications.

The lid and the obturator component were then put together and adjusted to fit the cast (Fig1-H). After trimming the acrylic extension into the surgical defect of the trial obturator base and leaving the oral part with the waxed-up artificial teeth already placed, the waxed-up obturator base was adjusted to the cast.
The twenty-six obturator trial bases underwent flasking and packaging using heat polymerized acrylic resin material (Acrostone heatcure material, Cairo, Egypt). The conventional method was used to finish and polish each obturator (Fig 1-I).

Implant installation (18)

Three dummy Dental implants (3.5mm width, 10mm length) (Dentium superline, Dentium Co. Ltd., Korea) were placed in each epoxy study model. The precise location of drilling was done with the aid of acrylic drilling template at canine, premolar and molar area on model I representing group I (Fig 2-A) while on model II that represent group II, the implants were drilled on central, premolar and molar location (Fig 2-B).

Cortical drilling was followed by pilot drilling, body drilling (core drilling), head drilling, and then body drilling once again to clear up the debris. The paralleling pin was used to verify the implants' parallelism. Using a torque wrench with 35N main stability, three implants (Dentium, Dentium Co. Ltd., Korea) each measuring 10 mm in length and 3.5 mm in diameter were placed in the pre-drilled holes. Proper sequence and depth of drilling for implants was followed to ensure proper placement and stability.

Pick-up of ball attachment (19)

Ball abutments (Rhein 83Srl, Bologna, Italy) were screwed to each implant under torque of 20 N using torque wrench. The attachments were then covered with their corresponding caps. The over denture obturator was positioned over the maxillary model. The attachments' locations were noted so they could be released once the obturator was fully placed. At the attachment points, three holes were drilled into the obturator's surface to let extra self-cure acrylic resin used for attachment cap pick-up escape . (Fig 3-A, B)
On the model, a separating medium (Acrostone separating medium, Cairo, Egypt) was used, and monomer was used on the relieved area.

Mixture of cold cure Polymethylmethacrylate was mixed. When the mixture had reached the dough stage, it was poured onto the fitting surface of the obturator (Fig3-C). The obturator was seated above the model to pick up the caps of the attachments. The caps were initially positioned in the fitting surface of the obturator (Fig 3-D). The acrylic resin was finished and polished. The twenty-six obturators were undergone the same process.

Assessment of outcome

Preparation of the models (18)

Stress analysis was evaluated by measuring strain distribution at the peri-implant area by using strain gauges (KYOWA strain gages, Kyowa Electronic instruments Co. LTD, 3-5-1, Chofugaoka, Chofu, Tokyo 182-8520, Japan). Six self-protected linear strain gauges of a gauge factor 2.13 ± 1%, a gauge length 1 mm, and a gauge resistance of 119.6 ± 0.4Ω each, were used for each model of this study as follow:
In each epoxy model, six channels were set up for the placement of six strain gauges.
Two channels were made at the buccal and palatal aspects of each implant to place the strain gauges (20).

There was a 2 mm thickness of epoxy resin between the strain gauge and the implant, and the channels were in the crestal region, parallel to the implant's long axis.
The strain gauge positioned on the flat wall of the channels, which was specifically created on the wall parallel to the implant.

Installation of the strain gauges (18)

In the epoxy resin models, strain gauges were positioned on the appropriate sites that had been established (Fig 4-A).

The strain gauge wires were inserted into specifically designed grooves made in the model's base to prevent accidental wire displacement that could have an impact on the readings' accuracy. (Fig 4-B).

The strain gauges were cemented parallel to each implant's long axis using a strain gauge adhesive (CC-33 Cement) supplied by the manufacturer.

The surface to be measured was indicated on the labels attached to each wire.

To record the developed strain, the six strain gauges of each model's wire terminals were linked to a multichannel strain meter (Data Logger model TDS-150, Japan) Faculty of Engineering, Alexandria University).

Fabrication of custom- made jigs and metal rods for the universal testing machine (18)

Three custom- made metal jigs were fabricated with 90^{o}, 45 ^{o}, 30 ^{o} angles to hold the epoxy models. These jigs had vertical plates to be inserted into the universal testing machine's lower member (Fig 5-A).

In order to apply load, two metal rods were made and joined to a horizontal metal bar with a vertical plate to be placed into the upper component of the universal testing machine (Fig 5-B). The tips of these metal rods were placed in the left and right first molars' central fossae (Fig 5-C).

Loading application and strain measurement (18)

Using the jigs, the model was fixed to the lower component of the universal testing machine.

The universal testing machine was linked to an individual computer, enabling computer-assisted software to precisely regulate the applied load and rate of speed (Fig 5-C).

Before loading, every strain gauge was calibrated and zeroed.

To measure the micro-strains caused by the applied load, the strain gauge sensors were connected to a strain meter that was connected to another computer. (Fig 5-C).

Vertical and oblique (30^{o}, 45$^{o)}$ load of 50N and 100 N were applied using universal testing machine. Through a metal rod, the load was applied in compression mode, and the cross-head speed was set at 10 mm/min.

The load was applied bilaterally, with metal rods guiding it towards the left and right central occlusal fossae of the first molars (Fig 5-C).

Under the identical circumstances, this process was performed for each obturator in the two groups that were studied.

Between each loading, there was a five-minute rest interval to allow the strain to dissipate.

Because multiple materials were used, each with a distinct elastic modulus (young modulus), it was difficult to come up with an equation to convert strain to stress. Furthermore, there is a clear correlation between strain and stress; as strain increases, so does stress (21).

Statistical analysis

Data were collected and reviewed properly. The normal distribution of the data was tested using Shapiro-Wilk test and Q-Q plots. All strain values were not normally distributed and were presented mainly median and inter quartile range in addition to mean and standard deviation. Comparison between groups was performed using Mann Whitney U test. Comparison of strain values between different angulations (30°, 45°, 90°) within each group was done using Friedman test followed by Dunn's post hoc with Bonferroni correction. Differences in strain values within each group between different loading (50 N and 100 N) were analyzed using Wilcoxon sign Rank test. All tests were two tailed. Significance level was set at p value≤0.05. Data were analyzed using IBM SPSS version 23.

Figure (1): A. Maxillary epoxy model with maxillectomy class IIA. **B.** duplicated stone casts. **C.** dental Typodont Standard Teeth mandibular model **D.** Two layers of base plate wax were adapted to the defect part. **E.** Heat polymerized acrylic resin (Acrostone heatcure material, Cairo, Egypt) was loaded into the area and processed**. F.** The interior part of the obturator was filled with soft plaster. **G.** A moist cellophane paper was adapted to the obturator part's edges **H.** The lid and the obturator component were then put together and adjusted to fit the cast **I.** Finished obturator.

Figure (2): A. Drilling of implants of model I through the acrylic templet. **B.** Drilling of implant of model II through the acrylic templet.

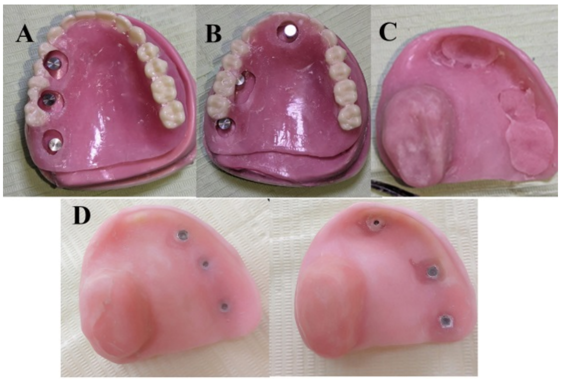

Figure (3): A, B Three holes were drilled into the obturator's surface to let extra self-cure acrylic resin used for attachment cap pick-up escape **C.** Mixture of cold cure Polymethylmethacrylate was mixed and poured onto the fitting surface of the obturator. **D.** The caps were positioned in the fitting surface of the obturator.

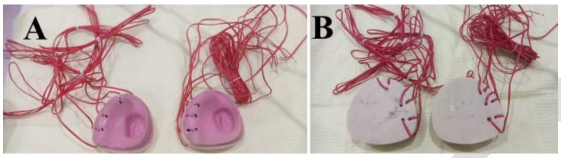

Figure (4): **A.** Installation of strain gauges in their prepared channels **B.** Channels in the base of the models in which strain gauges are embedded.

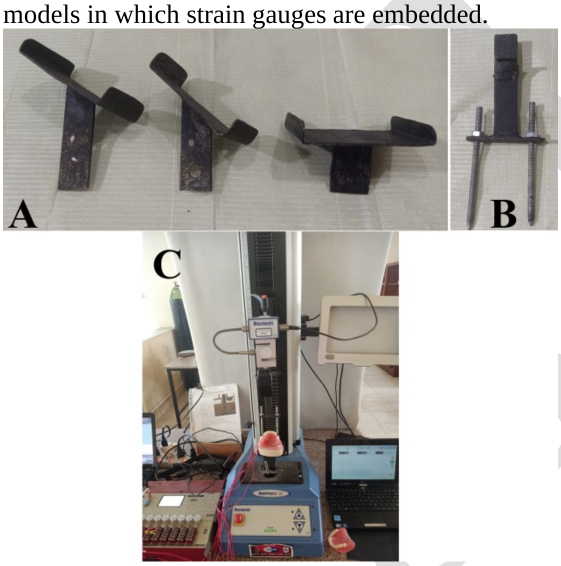

Figure (5): A. Custom-made jigs to hold the models **B.** Metal rods for load application **C.** The tips of metal rods were placed in the right and left central fossae of first molars and strain gauge sensors were connected to a strain meter that was connected to another computer to measure the micro-strains that result from the applied loading.

RESULTS

Strain forces were analyzed and compared between the study groups at 50 N and 100 N loading at different angulations (vertical, 30 ^{o} and 45 ^{o} oblique).

As regard the comparison of strain developed between both groups of 50 N loading at different angulations:

The strain median values obtained after application of 45^{o} oblique loading 50N and vertical loading 50 N in both groups, there was no statistical significance difference between the study groups with p value=0.407 and p value =0.927 respectively. Group II with nonlinear implant configuration showed less stress values but without significant values.

However, when comparing the strain median values developed after application of 30^{o} oblique loading 50 N between both groups, there was statistical significance difference between the study groups with p-value=0.007* indicating more strain forces among group I. The median values of each group are demonstrated in (table 1) and (graph 1).

As regard the comparison of strain developed at the same group of 50N loading at different angulations:

In groupI there was significance difference when comparing the load angulation at 50N for group I with p value of 0.004*. When comparing 30 ^{o} with 45 ^{o} oblique loading50N there was no significance difference with p value of 1.00. When comparing 30 ^{o} oblique loading 50N with 90 ^{o} loading 50N there was significance increase in strain values with 30 ^{o} oblique 50N loading and p value of 0.024. Also, when compare 45 ^{o} oblique 50N loading with 90 ^{o} loading 50N, 45 ^{o} showed more significant increase in strain values with p value of 0.007.

In groupII there was significance difference when comparing the load angulation at 50N for group II with p value of 0.010*. When comparing 30 ^{o} with 45 ^{o} oblique loading 50N there was no significance difference with p value of 0.392. Also, when comparing 30 ^{o} oblique loading 50N with 90 ^{o} loading 50N there was increase in strain values with 30 ^{o} oblique loading 50N but without significance difference and p value of 0.392. Also, when compare 45 ^{o} oblique loading 50N and 90 ^{o} loading 50N, 45 ^{o} oblique loading 50N showed more significant increase in strain values with p value of 0.007.

As regard the comparison of strain developed between both groups of 100 N loading at different angulations:

The strain values developed after application of 45 ^{o} oblique loading 100N and 90^{O} loading100 N between both groups there was no statistical significance difference between groups with p value was0.231 and p value was0.927 respectively.

However, on comparing strain values developed after application of oblique 30 ^{o} loading 100 N between both groups there was statistical significance difference between the study groups with *p* value was 0.002*indicating significance increase in strain values among group I. The median values and the results are demonstrated in (table 2) and (graph 2).

As regard the comparison of strain developed at the same group of 100N loading at different angulations:

In groupI there was significance difference when comparing the load angulation at 100N for group I with p value of 0.024*. When comparing 30 º oblique loading100N with 45 º oblique loading 100N there was no significance difference with p value of 1.00. When comparing 30 º oblique loading 100N and 90 º loading 100N there was increase in strain values with 30 º oblique loading 100N but without significance difference and p value of 0.176. Also, when compare 45 º oblique loading 100N and 90 º loading 100N, 45 º oblique loading 100N showed more significant increase in strain values with p value of 0.024.

In groupII there was significance difference when comparing the load angulation at 100N for group II with p value of 0.002*. When comparing 30 º oblique loading 100N with 45 º oblique loading 100N there was no significance difference with p value of 0.771. Also, when comparing 30 º oblique loading 100N with 90 º loading 100N there was increase in strain values with 30 º oblique loading 100N but without significance difference and p value of 0.070. Also, when compare 45 º oblique loading 100N and 90 º loading 100N, 45 º oblique loading 100N showed more significant increase in strain values with p value of 0.002.

Table (1): Comparison of strain forces between the study groups of 50 N loading at different angulations.

Angulation	Group I linear (n=13)		Group II non linear (n=13)		P value
	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	
30 º	210.83 (104.11)	183.54 (233.83)	117.58 (79.69)	101.20 (101.20)	0.007*
45 º	211.95 (99.15)	202.09 (194.12)	158.95 (68.82)	187.83 (132.33)	0.407
90 º	83.54 (76.45)	55.81 (98.44)	73.82 (42.68)	71.30 (85.10)	0.927
P value	0.004*		0.010*		
Pairwise	P1=1.00, P2=0.024*, P3=0.007*		P1=0.392, P2=0.392, P3=0.007*		

*Statistically significant differences at p value≤0.05, P1: comparison between 30° and 45°, P2: comparison between 30° and 90°, P3: comparison between 45° and 90°

Table (2): Comparison of strain forces between the study groups of 100 N loading at different angulations.

Angulation	Group I linear (n=13)		Group II non linear (n=13)		P value
	Mean (SD)	Median (IQR)	Mean (SD)	Median (IQR)	
30 º	280.79 (133.12)	237.67 (209.37)	148.59 (94.39)	144.77 (93.39)	0.002*
45 º	285.90 (163.71)	245.04 (305.21)	193.74 (88.48)	230.64 (169.21)	0.231
90 º	115.69 (103.59)	69.17 (138.44)	87.32 (49.16)	83.75 (93.83)	0.927
P value	0.024*		0.002*		
	P1=1.00, P2=0.176, P3=0.024*		P1=0.771, P2=0.070, P3=0.002*		

*Statistically significant differences at p value≤0.05, P1: comparison between 30° and 45°, P2: comparison between 30° and 90°, P3: comparison between 45° and 90°

DISCUSSION

Unsuitable loading is known to produce excessive stress and strain in the bone surrounding the implant, which can lead to bone resorption and implant failure. Therefore, it is important to investigate the mechanical responses in bone related to the configurations of implant placement (3, 4).

The objective of the current in vitro study was to assess the peri-implant stress distribution of obturators placed with three implants positioned using two different placement configurations.

In order to overcome the limitations of stress analysis studies conducted clinically, this study was conducted in vitro. The reasons for this were the difficulty in standardizing and reproducing the acquired values for strain measurement in vivo, as well as the precision with which stress distribution was evaluated (22).

A set of maxillary identical stone models of completely edentulous arch duplicated from maxillary epoxy model and opposed with standard typodent fully dentate mandibular model were used and mounted on a mean value articulator.

The maxillary arch chosen had maxillectomy class IIA according to Brown's classification (15) as previous studies showed that class II is the most common maxillectomy defect (23). Epoxy resin was used for implant placement because it has been reported to have an appropriate elastic modulus (about 20 GPa) for a material similar to bone. Additionally, it was easy to make and durable enough to resist repeated testing. (24).

To ensure standardization of all maxillary obturators during the arrangement of maxillary acrylic teeth, the mandibular standard typodont fully dentate model was kept on the articulator and the thirteen maxillary record bases changed on the same mounting to preserve the same maxillo-mandibular relation.

Implants were placed at the first study model at canine, premolar and molar as it was reported that the remaining alveolar crest after maxillectomy is suitable for implant placement in order to increase the comfort of the obturator (8). In terms of biomechanics, the posterior portions of an edentulous maxilla where the main functional occlusal stress occurs during chewing are an ideal location for endosseous implants (11). According to general guidelines for implant insertion, the canine and first molar are key positions and implants must be insert in these sites (25).

At the second study model implants were placed at incisor, premolar and molar as it was reported that in the anterior of the maxilla it is suggested that the incisor region receive one or two implants to lessen the impact of the arc form (26). Also, it is reported that because the anterior maxillary segment lies opposite the most retentive section of the defect, which is found along the posterior lateral wall, the residual pre-maxillary segment continues to be the most appropriate position for implants for the majority of maxillectomy patients. Furthermore, most patients have a sufficient volume and density of bone in the pre-maxilla, thus every attempt is made to maintain this portion of bone as much as(10).

Each implant had a diameter of 3.5 mm and a length of 10 mm. The 10 mm length was chosen since it's regarded to be sufficient for getting an optimal stress distribution around the implants. According to Georgiopoulos et al, (27) Reduced bone tissue strain was seen during both immediate and delayed implant loading when implant length increased from 10 mm to 14 mm. Implants smaller than 10 mm, however, had little effect on the strain field. Additionally, it was reported that the buccal and lingual walls at the crest of the intended implant location should have at least 1 mm of bone in order to give adequate bone thickness and blood supply around the implant for predictable survival (28). For this reason, a 3.5 mm diameter implant was used.

Due to the resilient quality of the Nylon caps female parts of the ball attachment system, which absorb and disperse stresses delivered to them more evenly , ball attachment was selected because research showed that, in implant retained obturators, it transmitted less stresses to the implants (11).

The strain that develops on the surface of the bone around an implant serves as an indicator of moments originating because it is impossible to detect the moments generated at an implant directly. Strain gauges fastened to the bone substitute material were used to achieve this (29). For this reason, in our study, there was a 2 mm thickness of epoxy resin between the strain gauge and the implant.

The strain gauges were installed in prepared flat surfaces in the epoxy resin parallel to the long axis of the implant and perpendicular to the crest of the ridge. This was done because it is recommended to bond the strain gauge on a completely flat surface to minimize the possibility of obtaining incremental apparent strain that results from mounting the strain gauge on a curved surface (30, 31).

Installing strain gauges on the crest of the ridge surrounding the implants is also justified by the fact that cortical bone compression at the alveolar crest around the implant's neck may cause overloading. Peri-implant stresses and bone loss usually begin at this location. Additionally, it was found that there was less stress in the implant's apical region. This finding can be attributed to the fact that there was significantly less bone directly in contact with the apical surface of a loaded implant than there was with the implant's remaining portion. As a result, the implant's apical region within the cancellous bone had little stress-induced stimulation (32).

The first molar was chosen for loading because it is frequently the site of the greatest occlusal forces and has the greatest contraction of the elevator muscles (33). In addition, first molars' central fossae were subjected to bilateral vertical and oblique static load as recommended by Tokuhisa et al (34) who noted that the area around the molar, where the denture displayed its greatest movement, was where occlusal force tended to be concentrated. At the same time, bilateral application of the load was done to mimic central occlusion in vivo.

Because of the usage of varied materials with varying modulus of elasticity, it was challenging to develop an equation to convert strain to stress. However, strain and stress are directly correlated; as strain increases, so does stress. In our study, stress analysis and distribution at the peri-implant tissues were evaluated by using strain gauges to measure strain on an object (21).

Between 50 and 100 N was found to be the average biting force of individuals who were completely edentulous and wearing implant assisted overdentures (34, 35). For this reason, it was chosen as the amount of load applied to the obturator in this study.

In the current study, loading was done both vertically parallel to the long axis of the implant and obliquely (30º and 45º). This application of oblique loading was carried out in accordance with Lin et al.'s (36) observations that inclination of prosthetic tooth cusps causes mastication forces more oblique, and strains from oblique forces are particularly important to record since they are a greater risk than vertical forces.

According to the results of applying vertical load in the study, there was no statistically significant difference in strain values between both studied implant placement configurations in spite of increasing the magnitude of vertical loading from 50 N to 100 N. This could be attributed to magnitude of the vertical forces that were directed within the long axis of the used implants and attachments which were parallel to each other. This attribution can be supported by the record of Bahuguna, Bahuguna et al (37) The non-axial load places greater gradients of tension on the implant and the peri-implant bone, whereas the axial force is the most favorable since it distributes the tension more uniformly throughout the implant. Simultaneously, the rubber ring inside the metallic capsule of the ball attachment system's socket may absorb or distribute the stress it experiences evenly (11) without concerning the implant configuration.
There were higher strain values of group I than group II which accepted with that Throughout the alveolar ridge, implants are positioned from anterior to posterior for a more advantageous load distribution (38) demonstrated that a dispersed implant configuration results in a more favorable distribution of bone stresses than a concentrated implant arrangement and cantilever, Implants placed equidistantly avoid abutment loosening, retainer wear, and instability.

It was observed that, there were higher strain values of the oblique loading compared to the vertical loading this result is in agreement with the result of M.M. Amer et al (39) and this could be attributed to the fact that non-axial forces frequently result in an uneven distribution of stresses, producing regions with higher and lower stresses. This coincides with the findings of Abdel Aal, M (11), that the load direction affects the stresses values. According to this finding, it's critical to reduce the stress caused by lateral forces by removing early occlusal contacts, choosing an occlusal scheme carefully, and using a wide range of stabilizing elements.

On the contrary, Neena A (17), reported that when vertical loads rather than oblique loads were applied to the overdenture, implants shared more stresses. He explained that the mucosa lining the crest of the alveolar ridge will share in support when vertical loads are applied to an overdenture. The mucosa lining the crest and the lateral slopes of the alveolar ridge will share support when an oblique load is applied, creating a wider surface to dissipate stresses and lowering the value of the maximum stress.

Also, there was statistically significant difference between both implant configurations upon application of 30º oblique loading of magnitude 50 and100 N with favorable strain values in groupII with nonlinear configuration.

However, various studies showed that the most anterior implant experienced the highest peak stresses. Clinical studies that demonstrated that implants placed adjacent to defects had a higher marginal bone loss rate than implants inserted posterior to them are consistent with this finding (11). The reason behind this could be the way the obturator rotates when it is in use; the defect side rests on soft tissue, resembling a cantilever, while the other side is supported by the implants and residual ridge. In order to have a predictable long-term implant success in certain circumstances, it is advised to insert wide, long implants there whenever possible.

As regard to our observations of favorable stress distribution especially upon application of oblique loading of direction 30º and 45º of group II with nonlinear configuration in which three implants placed at incisor, premolar and molar we supported the use of this implant placement configuration for class IIA maxillectomy implant retained obturators.

Nevertheless, given the wide range of maxillectomy classes, one of the study's limitations is that it might not be possible to generalize the findings to them all. The findings may therefore only be relevant to maxillectomy class II due to variations in the degree and character of soft tissue and bone loss amongst classes (15). Furthermore, the stresses evaluated in this investigation were only during the application of forces that replicated chewing and mastication; strains were not measured during the dislodging of the obturator, which could have resulted in different patterns of strain distribution that could have an impact on the obturator's and the attachments' longevity (40). An additional limitation is that strain gauges only record stresses at the precise location on which they are put, which may make it impossible to see the stress patterns over the entire model as they would be visible in the case of photoelasticity analysis (40). Furthermore, the oral cavity was not entirely replicated in this in vitro investigation, thus it is recommended to use the same clinical assessment procedures (intra-oral) to look into the clinical efficacy of both implant placement configurations for implant-retained obturators. further, examine the effectiveness of the implant placement distribution for other maxillectomy classes with various attachment designs. Analysis of stress distribution patterns utilizing different evaluation techniques, particularly the recent Digital Image Correlation method.

CONCLUSION

Considering the limitations of the research and based on the results, it was determined that nonlinear implant placement configuration had superior biomechanical performance with the lowest strain values surrounding the dental implants when exposed to forces imitating mastication and functional forces. Therefore, the authors suggest using that nonlinear implant placement configuration for achieving favorable stress distribution.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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