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Tilted Versus Short Implants Supporting Mandibular Fixed Detachable Prosthesis (In Vitro Study)

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ABSTRACT

Purpose: This study aimed to evaluate strain induced in implants supporting fixed detachable prosthesis with different implant protocols using strain gauge analysis. **Material and methods**: This stress analysis study used two 3D models simulating a completely edentulous lower arch to support and retain fixed detachable prostheses. In the first model four implant beds were considered; two anterior implants oriented axially and two posterior implants placed at the premolar region tilted 30 degrees. In the second model implant beds were designed with two anterior implants oriented axially and two short posterior implants 8 mm length placed in the first molar region oriented axially. Standardized static load was applied unilaterally by using a loading device (universal-testing machine). Strain gauge was used to measure strains induced in each implant. **Results:** Regarding the loaded side: Strain induced in the anterior implant and in the lingual and distal aspect of the posterior implant in the first model has shown higher strains compared to the second model. This difference was statistically insignificant in the anterior implant and in the lingual aspect of the posterior implant, while strains induced in the distal aspect of the posterior implant was statistically significant higher in the first model compared to the second model. **Conclusion:** With the limitation of this in vitro study, it can be concluded that short implants induce less stresses distally than tilted implants.

KEYWORDS

Strain gauge,
3D printed models, Implants,
Fixed detachable prosthesis

INTRODUCTION

The fully edentulous elderly patient is one of the common cases that requires rehabilitation in the field of prosthodontics. Options such as implant supported removable overdentures, implant retained dentures and implant-supported fixed dentures are now available for these patients. Dental implants became a successful treatment option

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to replace missing teeth with long term survival and success rates [1].

The goal of restoring partially or completely edentulous patient is providing a prosthesis with long-term success, function and patient satisfaction. Patients are generally more satisfied with fixed prosthesis. Fixed detachable prosthesis (Screw-Retained Dentures) is a reliable alternative treatment when fixed prosthesis does not satisfy the patient in respect to esthetics, phonetics, oral hygiene and oral functions [2].

In order to place implants in the posterior edentulous mandible, bone grafting surgeries usually needed to increase the bone height and width. The drawbacks of bone grafting surgery include the need of more treatment time and cost, this made placing dental implants posteriorly more difficult [3].

It was reported that in edentulous mandible the chewing forces are concentrated posteriorly so the bone remodeling and resorption is mainly in the posterior region. Treatment of a completely edentulous mandible with removable overdenture supported and retained with conventional implants placed interforaminally was a routine successful treatment with an appropriate success rate [4].

Another conservative approach to the restoration of posterior mandible is the use of short implants. Many authors have reported that the clinical longevity of short implants is comparable to rehabilitations with conventional implants associated with graft surgery. However, several studies recommended extra care when using short dental implants. The risk of their failure is slightly high [5-10] .

Another approach to restore posterior mandible with compromised bone quality and/or quantity is the "all-on-4" concept. In the mandible this concept includes placing four implants interforaminally to support fixed restoration. The distal implants are angled to avoid the inferior alveolar canal [11].

The idea behind tilting the distal implants is to place the implants' platform more distally. This increases the anterior-posterior distance (A-B spread) between the mesial and the distal implants allowing to decrease the cantilever extended posteriorly. Increasing the A-P distance is a better biomechanical situation. The all-on-4 concept allows clinicians to deliver fixed dental prostheses[12,13].

All resin-based hybrid prostheses had large number of advantages. Among these advantages, the low cost, the reduced impact force of dynamic occlusal loads and being a highly esthetic restoration. Furthermore, they may be successfully used by a combination of tilted and axially placed implants in the posterior part of the arch especially in case of resorption. However, some disadvantages like speech difficulties, food impaction, difficulties in dealing with hygiene or liability to fracture were reported [14].

Several methods have been introduced to evaluate the stresses and strains generated around dental implants such as photoelasticity, strain gauges, finite element method and three-dimensional digital image correlation. Among them strain gauge was a common and a reliable method [5, 15].

Since there are limitations on the use of strain gauges, first, they should be isolated completely from saliva and blood. Secondly, they must stick firmly to the surface being measured to accurately measure strain. Thirdly, they can only measure strain at one point and in one direction; rosette strain gauges are required to determine the complete two-dimensional strain. In attempt to control some of these limitations using strain gauge in vitro is more common and more reliable [16].

With the advance of digital dentistry, 3D printed casts had several advantages including high abrasion resistance, minimal fracture risk, light weight and the ability of manufacturing multiple replicas at the same time. Conventional stone casts are susceptible to abrasion, fracture and deformation in addition to the long processing time [17,18].

MATERIAL AND METHODS

On an educational mandibular stone model for a completely edentulous arch a complete denture is constructed by the conventional method. Self-cured acrylic resin was adapted on it, teeth setting for the denture was done according to the anatomical and mechanical considerations and waxing up was performed.

The center of the laterals, first premolars and first molars were marked on the cast by small indentations.

Construction of the 3D models was performed. The stone model was scanned by 3 Shape desktop scanner and a Stereolithographic (STL) file was created.

Flasking, wax elimination, packing and curing of the heat cured acrylic resin (Vertex regular acrylic denture base, Vertex-dental, The Netherlands), followed by finishing and polishing of the denture was done.

The denture was then duplicated into another identical denture. Each denture was tried to fit on a stone model identical to the one the denture constructed on.

In the STL file implant beds were designed in the planned implant sites. In the first model four implant beds were considered, two anterior implants in the lateral position, 11 mm length and 3.5 mm diameter oriented axially and two posterior implants placed in the premolar region tilted 30 degree. (Fig. 1)

In the second model implant beds were designed with two anterior implants in the lateral position 11 mm length and 3.5 mm diameter oriented axially and two short posterior implants 8 mm length placed in the first molar region oriented axially.

Grooves were designed at each future implant site for the attachment of the strain gauges, one groove lingually for each anterior implant and two grooves distally and lingually for each posterior implant.

A key index with 2 mm thickness and 2 mm offset with tissue stops was designed for creation of a space for the mucosa simulator. For the construction of the mucosa simulator, narrow groove was designed for interlocking to facilitate its insertion and removal.

The STL files were sent to the additive manufacturing machine for printing the models and the index. The raw material used in production of the printed products is a photopolymer, which is a mixture of acrylic acid esters and photo initiator. (Fig. 2)

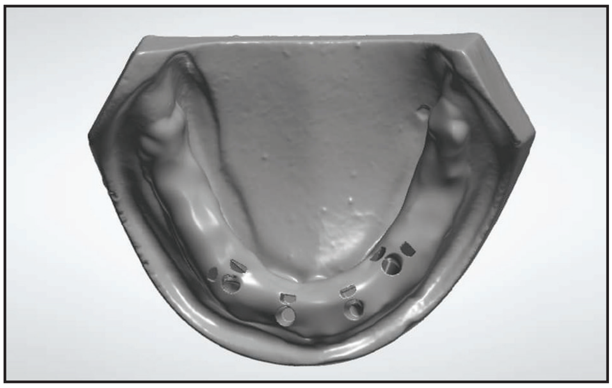

Figure (1): Generated STL file

Figure (2): 3D printed cast

Self-cure acrylic resin was mixed and applied to fix the implants in their implant beds. After implant insertion, mucosa simulation was done via Multisil-Mask soft rubber base material (Multisil-Mask soft Bredent, Senden, Germany).

Multisil-Mask soft is an addition-linking silicone which is injected from the double-mix cartridge directly into the printed index, which was seated over the model. This index had 2 mm even offset with tissue stops. This way reproduction of the mucosa with 2 mm even thickness on the working models was achieved.

Converting complete lower denture to fixed detachable prosthesis:

For model I, angled multiunit abutments (Multiunit abutment, Implant Direct, USA); (screw-retained abutments) were attached on the posterior implants whereas straight multiunit abutments were used on the anterior implants using hex screw driver to ensure parallelism. Straight multi-unit abutments were used for model 2.

The titanium sleeves (Titanium sleeves, Implant Direct, USA) were screwed into place on the multiunit abutments to evaluate the part that needs to be removed. Holes were drilled through the pre-made dentures at the proposed implant positions. The holes were enlarged so that the dentures could be passively seated in position and the dentures were placed over the titanium sleeves to check passive fit.

Reduction of titanium sleeves' height was done by using a marker (red high spot indicator) to mark proper height of the sleeves to the level of occlusal plane before pick-up step. The sleeves were unscrewed from the multi-unit abutments and trimming of excess height was done by using metallic disc till the previously determined mark. Sleeves were screwed to the multi-unit abutments and hollowed out dentures were reseated.

All undercuts around the implants and the titanium sleeves were blocked out with rubber dam. Small piece of cotton was used on the top of the screw access of the titanium sleeves.

Self-cured acrylic resin was used for the attachment of the titanium sleeves previously installed over the implants in the lower dentures.

Cold curing acrylic resin was injected around the sleeves and with the holes created in the denture. The denture was seated and excess resin on the top access of the sleeves was removed till the resin was totally set. (Fig. 3)

Cotton pieces positioned on the top of the sleeves were removed with explorer probe and with a uni-grip screw driver the prosthesis was unscrewed. The prosthesis was finished, the lingual, labial and buccal flanges were trimmed and any sharp angles or edges were removed and the prosthesis was screwed.

The strain gauges used in this study were supplied with fully encapsulated grid and attached wires. The wire used for the strain gauges was insulated by a packing material. The strain gauges were then installed in their grooves. All strain gauges were positioned parallel to the long axes of the implants. (Fig. 4).

Figure (3): Picked up overdenture

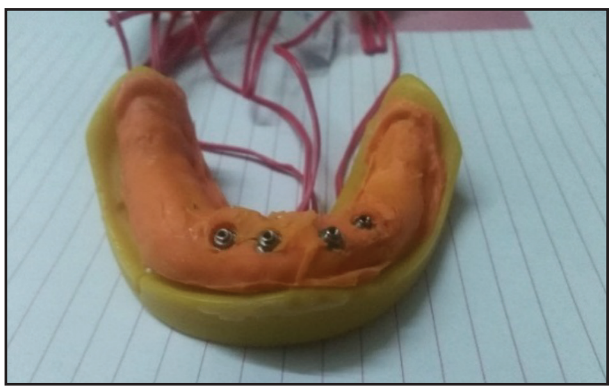

Figure (4): Strain gauge installed

A T-shaped load applicator was made to fit on the denture teeth unilaterally. Simultaneous and even contacts between the terminal ends of the load applicator and the artificial teeth on the loaded side of the model was achieved by spot grinding guided by articulating paper markings.

A loading device (universal-testing machine) was used to apply standardized static load. Loads were applied unilaterally with magnitude of 100 N. The applied load started from zero up to 100N. Once the load was completely applied, the micro strain readings were transferred to micro strain units from the channels strain meter.

RESULTS

In the first model "all on four model: Regarding the loaded side, the strain induced in the lingual aspect of the anterior implant lingually was 61.22±11.2, while in the posterior implant was 117.4±15.8 and 140.8±11.6 lingually and distally respectively.

Regarding the unloaded side, the strain induced in the lingual aspect of the anterior implant lingually was 19.9±1.5 and in the posterior implant was 23.9±3.1 and 20.6±2.23 lingually and distally respectively.

Paired t test was used to compare between loaded and unloaded sides and a higher significant difference was found in the loaded side compared to the unloaded side in all measured sides of the implants. The significant level was set at P ≤ 0.05. (as shown in table 1 and fig. 5)

In the second model "short implant model" regarding the loaded side, the strain induced in the lingual aspect of the anterior implant lingually was 45.9 ±10. 4 and in the posterior implant was 78.1 ± 11.8 and 107.1 ± 20.2 lingually and distally respectively.

Regarding the unloaded side, the strain induced in the lingual aspect of the anterior implant lingually was 25.8 ± 4.4 and in the posterior implant was 25.9±3.4 and 19.9±5.3 lingually and distally respectively.

Paired t test was used to compare between loaded and unloaded sides and a higher significant difference was found in the loaded side compared to the unloaded side in all measured sides of the implants (as shown in table 1 and fig. 6).

Table (1): *Mean and standard deviation of strain induced in different sides of implants in both models*

The first model			
	Anterior lingual Mean ±SD	Posterior lingual Mean ±SD	Posterior distal Mean± SD
Loaded side	61.22 ±11.2	117.4 ±15.8	140.8 ±11.6
Unloaded side	19.9 ±1.5	23.9 ±3.1	20. 6 ±2.23
P value	0.003	0.0005	0.0001
The second model			
	Anterior lingual Mean ±SD	Posterior lingual Mean± SD	Posterior distal Mean ±SD
Loaded side	45.9 ±10. 4	89.1 ± 11.8	101.1 ± 20.2
Unloaded side	25.8 ± 4.4	25.9 ± 3.4	19.9 ± 5.3
[value	0.03*	0.008*	0.002*

*SD; Standard Deviation *: Significant at P ≤ 0.05,*

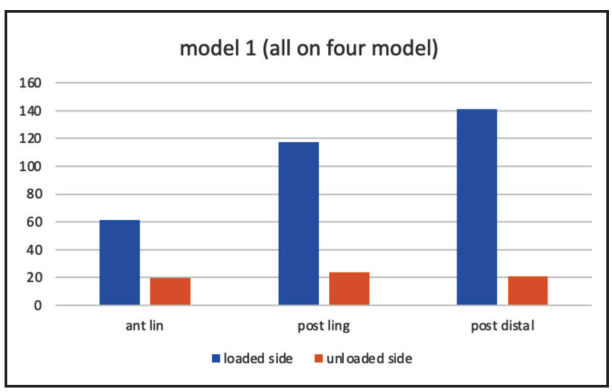

Figure (5): Bar chart showing mean of strains induced in the first model

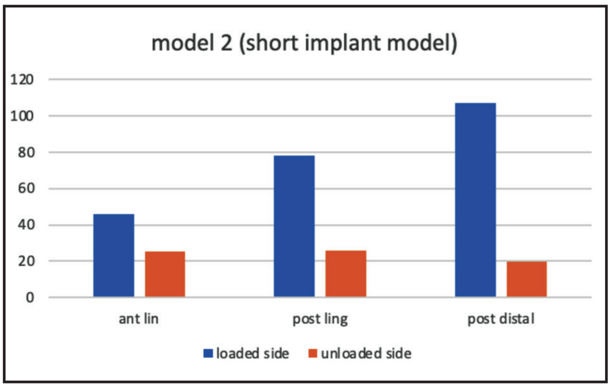

Figure (6): Bar chart showing mean of strains induced in the second model

Unpaired t tests were used to compare between the two models. (Table 2)

Table (2): *Mean, standard deviation and P value of strain induced in different sides of implants in both models*

Loaded side			
	The first model Mean ±SD	The second model Mean ±SD	P value
Anterior lingual	61.22 ±11.2	45.9 ±10. 4	0.1
Posterior lingual	117.4 ±15.8	89.1 ± 11.8	0.06
Posterior distal	140.8 ±11.6	101.1 ± 20.2	0.04*
Unloaded side			
	The first model	The second model	P value
Anterior lingual	19.9 ±1.5	25.8 ± 4.4	0.09
Posterior lingual	23.9 ±3.1	25.9 ± 3.4	0.4
Posterior distal	20. 6 ±2.23	19.9 ± 5.3	0.08

SD; Standard Deviation **: Significant at* $P \leq 0.05$.

Regarding the loaded side: strain induced in the lingual aspect of the anterior implant and in the lingual and distal aspects of the posterior implant in the first model showed higher strains compared to the second model. This difference was statistically insignificant in the anterior implant and in the lingual aspect of the posterior implant, while strains induced in the distal aspect of the posterior implant were statistically significant higher in the first model compared to the second model.

Regarding the unloaded side: statistically insignificant difference was found between the strains induced in both models in all measured sides of the implants.

DISCUSSION

In the first model the implants were arranged according to the concept of tilting the distal implants in the edentulous arches. This technique was known as "All on Four" concept. This concept had several advantages such as the use of the fewer number of implants, shorter cantilever length and avoidance of more complicated surgical procedures [(19)].

In the second model short implants were placed posteriorly. This concept is an alternative prosthetic option for atrophic ridge which may provide several surgical advantages including reduced treatment time and costs [(20)].

When fixed restoration didn't satisfy the patient in terms of esthetics, phonetics, oral hygiene and functions; fixed detachable prosthesis (Screw-Retained Dentures) is a reliable alternative treatment. Using acrylic resin-based prosthesis as a restoration for an immediately loaded implants is commonly used and acceptable [(21)].

Strain gauge technique was used for stress analysis in this study. It is a well-known accurate method for stress analysis. It measures strains induced into a loaded structure by converting the change in resistance of an electric wire into strain measurement [(22)].

It was stated that measurement of strain in vivo directly from bone using strain gauge is difficult and have several limitations such as isolation from saliva and fixation, so this study was performed in vitro [(16)].

Scanning of the models and creation of STL files were performed and utilized in this study, as assessment of the accuracy of the STL files after complete arch digital scans was performed in vitro and found to be comparable or even more accurate than conventional impressions [23,24].

The load applied to first molar was 100 N in order to correspond with the moderate chewing force of implant supported overdenture. Unilateral loading was applied to be similar to the chewing activity which occur unilaterally [25,26].

In a study that worked on the accuracy of the 3D printed casts and their deviation from stone master cast, it was found that there is a difference, but that difference was within the acceptable range for clinical applications. So, this study was conducted on 3D printed casts to avoid some disadvantages of the stone casts such as liability to wear or fracture[27].

In both models, a higher significant difference was found in the loaded side compared to the unloaded side in all measured sides of the implants as it is well known that the implants which are in close proximity to the loading point show higher stresses than other implants farther from it [28].

Higher strains found in the distal surfaces of the tilted implants may be due to the unfavorable loading direction. The presence of distal tilted (all-on-four) implants would result in higher stress compared to vertical implants. This was accepted and reported in other studies [29,30].

A study worked on crestal bone loss around implants with different diameters found that higher crestal bone loss accompanied small diameter implants compared with conventional implants with standardization of all other factors. The result of another study has shown that implant diameter was more important for improved stress distribution than implant length. This may explain the lower strain found in the short implants compared to the tilted ones [28,31].

The results of this study were in acceptance with another finite element study that worked on four software models containing short, tilted and straight implants with and without cantilever. The highest stress value was found in the tilted implants model with cantilever. The lowest stress value was found in the short implant model without cantilever [32] .

However, the results of this study were not in acceptance with a study worked on two variables: implant length and implant angulation. This finite element study used six atrophic mandibular models and found that using short implants tilted distally 45 degree were more favorable biomechanically than implants placed vertically [33].

It Could be deduced that short implants decrease the chance of implant overloading with observation of limitation of this in vitro study compared to the clinical situation. Bone quality, nature of the bone-implant interface, loading conditions and material properties are important biomechanical factors that influence stresses transmitted from implant to bone [34,35].

CONCLUSION

With the limitation of this in vitro study, it can be concluded that short implants induce less stresses distally than tilted implants when used to support and retain a fixed detachable prosthesis.

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