In vitro stress analysis study of different prosthetic options using single posterior implant for management of mandibular unilateral distal extension saddle

I.A. Dahab*, A.A. El-Gendy, I.R. Eltorky

Prosthodontics Department, Faculty of Dentistry, Tanta University, Tanta, Egypt

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Abstract

Aim: The aim of this study is to compare in vitro, micro-strain induced by different prosthetic options using single posterior implant in lower unilateral distal extension saddle (Kennedy class II).

Materials and methods: For this study, three prosthetic designs were made I, II, and III on epoxy resin model representing mandibular unilateral distal extension edentulous area with the second premolar as the main abutment and implant was placed at the site of the second molar. For group (I), The design principle was (RPI clasp on the second premolar abutment, lingual bar major connector, double Aker clasp on the first and second molar on the other side and (ball & socket) attachment on the implant). For group (II) the design principle was ((RPI clasp on the second premolar abutment and (ball & socket) attachment on the implant)). For group (III) implant tooth connected fixed partial denture was fabricated using the 2nd premolar as mesial abutment and the implant as distal abutment. A self-protected linear strain gauge was used for this study to measure the micro-strain induced on the buccal and lingual sides of the implant and 2nd premolar abutment.

Results: SPSS software program was used in the statistical analysis of the results. The results revealed that Maximum stresses induced at tooth and implant abutments were in case of group (II) design and distribution of micro-strain between the implant and tooth abutment in case of group (III) design was better than distribution in cases of the two other groups.

Conclusion: The conclusions are as follows: (1) maximum strain induced at tooth and implant abutments were in case of side plate design; (2) distribution of micro-strain between the implant and tooth abutment in case of fixed restoration was better than distribution in case of the other two groups.

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Keywords: Implant; Stress analysis; Partial over denture

1. Introduction

Posterior free end edentulous areas are more prevalent among population. Absence of posterior abutments to support and retain partial dentures
affects the prognosis of prostheses. A problem of support, retention and stability is usually associated with distal extension removable partial dentures (RPDs) [1,2].

One of the most challenging situations requiring treatment with RPD is cases classified as Kennedy class II. Being unilateral and free end with abutments only on one side of the edentulous area create a long lever arm resulting in an unstable removable prosthesis [3].

The restoration of distal extension RPD requires planning following biomechanical design principles. Obtaining adequate support, retention and stability from both the ridge and abutments should be designed without eliciting any harm to the supporting structure [2].

The use of posterior implants has been suggested for stabilization of the distal extension bases in the vertical direction and to carry the retentive elements for partial overdentures [4]. Placement of posterior implants if anatomically possible, converts the edentulous defect from a distal extension Kennedy Class I or II situation to a more biomechanically favorable Kennedy Class III category [5].

The placement of endosseous osseointegrated implants under a removable prosthesis was proved to provide bone preservation, prosthetic retention, stability, and a degree of occlusal support resulting in improved function, facial esthetics and comfort [6].

Tooth-implant connection by means of prosthetics remains a controversial issue due to the disparate results obtained in the various studies that have been conducted around the world. The differences in the union between an osseointegrated implant and natural tooth's union to the alveolar bone lead to difference in response to the different masticatory forces, both natural and pathological. A number of published studies and articles have dealt with this issue in very different ways: bibliographic reviews [7], in vitro studies [8], in vitro biomechanical studies [9], and clinical case studies [10].

A strain gauge is a device used to measure the strain of the object. The most common type of strain gauge consists of an insulating flexible backing that supports a metallic foil pattern. The gauge is attached to the object by a suitable adhesive. As the object is deformed, the foil is deformed, causing its electrical resistance to change [11].

Latest studies published with strain-gauge analysis show the use of this method to examine the biomechanical aspects of over denture with different attachment system, to measure the force transmission onto implants supporting overdentures and to assess the deformation of abutments of different heights in mandibular cantilevered implant-supported complete prosthesis [12−15].

So the aim of this in vitro study is to evaluate strain induced by different prosthetic options using single posterior implant in lower unilateral distal extension saddle (Kennedy class II).

2. Materials and methods

In this in vitro study, strain gauge technology was used to compare the stresses induced by different prosthetic options using single posterior implant for restoring lower unilateral mandibular distal extension saddle (Kennedy class II).

2.1. Fabrication of the mandibular epoxy model

Commercially available rubber maxillary and mandibular models with acrylic teeth were used. This model contained anatomically shaped teeth with roots which can be inserted and removed from the model. The 1st and 2nd molars were removed from the rubber model unilaterally and their root sockets were blocked with wax.

An impression for this modified cast was made using silicon rubber base impression material. The remaining teeth were removed from the rubber model and their roots were wrapped with 0.3 mm thickness tin foil material to simulate the dimensions of the periodontal ligaments and then inserted in their positions in the impression. Epoxy resin material was poured into the silicon impression. After complete polymerization, the epoxy model was removed from the silicon rubber impression. The tin foils surrounding the roots of the teeth were removed. The acrylic sockets and the roots of the teeth were painted with rubber base adhesive and allowed to dry. Light body silicon rubber impression material was injected in the sockets of the teeth then the teeth were repositioned in their places inside the model.

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1 Nissin dental products incKyoto Japan.
2 Cavex Set Up Regular modeling Wax, Holland BV. Haarlem, The Netherlands.
3 Speedex, coltene A.G., Alsatten, Switzerland.
4 Kemapoxy 150 JM, CBM International.
5 Zetaplus adhesive, Zhermack, Italy.
2.2. Fabrication of drilling guide template and implant installation

The drilling guide template is an acrylic replica of the trial denture that replaces the missing teeth to control the position of the implant related to the position of the second molar.

A round bur was used to drill a hole through the stent into the epoxy resin model corresponding to second molar in the edentulous area. The direction of the hole was checked for parallism by the dental parallometer.6

One implant fixture7 of size 13 mm length and 4.2 mm diameter was used at the site of the second molar in edentulous side of the model.

2.3. Installation of strain gauges

A self-protected linear gauge8 was used for this study as follow:

1. Small channels were prepared in the epoxy model at the buccal and lingual surfaces of the implant and the abutment 2nd premolar tooth to receive the strain gauge rosettes.
2. The channels were about 4 mm length below the crest of the alveolar ridge and parallel to the long axis of the abutment tooth and the implant with depth to leave just 1 mm thickness of epoxy between the strain gauge rosettes and abutment or implant. The channels were prepared with flat walls especially the walls parallel to the implant and the abutment on which the strain gauge will be mounted.
3. Four strain gauges were installed on the selected sites on the epoxy model to measure the microstrains in the medium surrounding the abutment tooth and implant, respectively.
4. A strain gauge adhesive9 was used to cement the strain gauges parallel to the long axis of both implant and abutment and held in their sites for 5 min using Teflon sheets supplied with the gauges as recommended by manufacturer to avoid adherence of the cement to the hands (Fig. 1).
5. The strain gauges were covered by self-cured acrylic resin.

2.4. Simulation of mucosa covering the residual ridge

According to Elgendy [21], light body rubber base impression material was used to simulate the oral mucosa covering the ridge through the following steps:

1. The residual ridge and retromolar area surfaces were covered by two layers of base plate wax of 2 mm thickness to act as a spacer.
2. A stone10 index was constructed and extended on the model buccally and lingually to act as a stopper for accurate repositioning. After hardening of the index, the wax was removed from the ridge.
3. The ridge was painted with rubber base adhesive11 and the fitting surface of stone index with separating medium.
4. The stone index was packed with light body rubber base impression material and then repositioned over the model with firm hold until complete setting.

On the prepared epoxy resin model, different prosthetic designs were constructed as follows:

- Group I: (cross arch stabilization partial over denture)
- Group II: (side plate partial over denture)
- Group III: (fixed partial denture)
- Group I: removable partial over denture (RPOD) was constructed according to this design principle: RPI clasp on the second premolar abutment tooth, lingual bar major connector, double

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6 AF30 Universal Milling Machine, Switzerland.
7 TUT Dental Implant.
8 Koyoma Srain Gages, Japan.
10 Elite Stone.
11 Zetaplus adhesive, Zhermack, Italy.
Aker clasp on the first and second molar on the dentulous side. Ball & socket attachment is used on implant abutment to retain the RPOD (Fig. 2).

- Group II: the side plate removable partial overdenture (RPOD) is constructed according to this design principle: RPI clasp on the second premolar abutment tooth. Ball & socket attachment is used to retain the RPOD (Fig. 3).
- Group III: implant tooth connected fixed partial denture was fabricated using the 2nd premolar as mesial abutment and the implant abutment as distal abutment (Fig. 4).

2.5. Loading device

2.5.1. Fabrication of acrylic biting block

- Each design is adapted on the cast that is mounted on a semi adjustable articulator.
- The post of the articulator is opened to make the upper and lower cast slightly apart.
- A 3-mm thickness horseshoe shaped wax wafer is placed between the upper and lower cast and the articulator was closed to get the imprints of the teeth in the wax.
- The right and left sides of the wax wafer are connected by wax bar at the molar region 6 cm lengths and 5 mm thickness. The bar was extended from the 1st molar in one side to the 1st molar on the other side.
- The wax wafer is flasked and converted to acrylic bite block.
- After deflasking, the acrylic bite block is finished and indentation is made at the middle of the bar to identify the point of the loading to allow the distribution of the load all over the lower cast.

2.5.2. The loading was in the following manner

For each design,

- The design is placed in its position in the epoxy model then the acrylic bite block is placed in its place on the occlusal table of the model.
The model was attached to the base of fully digitized testing machine (LLOYD instrument) in a horizontal plane.

The Lloyd was connected to a personal computer through computer aided software to allow for the accurate control of both amount of the applied load and duration (Fig. 5).

The strain gauge sensors were connected to a strain meter to measure the micro-strains that result from the applied load.

Ascending load is applied at the acrylic bite block from 0 to 200 N with the loading tip of the device on the loading point of the acrylic block.

The strain meter measure the strain every 1 N and record it in computer.

Five minutes were left between each loading as period of rest to allow for heat dissipation.

The load is applied 10 times for each design.

2.6. Statistical analysis

The data was collected, tabulated and statistically analyzed using ANOVA and TUKEY’S analysis tests using SPSS software program.

3. Results

Analysis of micro-strain measurements around the tooth abutment and implant abutment under the three different designs are shown in Tables 1–3 and Graphs 1 and 2.

The minimum micro-strain measurements were recorded in gp III (mean = 12.774) followed by gp I (mean = 18.851) then gp II (mean = 44.343).

The difference was statistically significant between gp I & II and gp I & gp III as P value <0.001*. However the difference was not statistically significant between gp II & III as P value =0.246.

The micro-strain measurements at the four sites of the strain gauge sensors were analyzed using SPSS software program.

The difference of micro-strain measurements between the three groups at lingual side of implant was significant as P-value <0.001*.

The maximum micro-strain measurements recorded at the lingual side of the implant were found in group II followed by group I and the least micro-strains were in group III.

At the buccal side of implant, difference of micro-strain measurements between the three groups is significant as P-value <0.001*.

The maximum micro-strain measurements recorded at the buccal side of the implant were found in group II followed by group I and the least micro-strains were in group III.

At lingual side of abutment, the difference of micro-strain measurements between the three groups is significant as P-value <0.001*.

The maximum micro-strain measurements recorded at the lingual side of the abutment were found in group II followed by group III and the least micro-strains are in group I.

At buccal side of abutment the difference of micro-strain measurements between the three groups is significant as P-value <0.001*.

The maximum micro-strain measurements recorded at the buccal side of the abutment are found in group II followed by group III and the least micro-strains is under group I.

4. Discussion

Freitas et al. stated that implant placement on the molar region can provide better biomechanical configuration, changing Kennedy class I or II to class III [16].

For accuracy of the evaluation and because of the difficulty in standardization and repeatability of the obtained values for strain measurement in-vivo, this study was conducted in-vitro to overcome limitations of stress analysis studies attempted clinically [17].

The model was prepared from epoxy resin material which has an appropriate elastic modulus for a bone analog material (approximately 20 GPa) [18].
The incidence of bone resorption is greater in mandible than in the maxilla so mandibular case was used in this study to reduce the risk of bone resorption [19].

Because bone is not a homogenous material, predictions of stress magnitude and stress transmission in the human mandible based on the results of this study must be done with caution [20].

In this study the roots of the abutment teeth were lined with 0.3 mm thickness of light body silicone rubber impression material, while the residual ridges were covered by 2 mm thickness of the same material for simulation of mucosa which has more resiliency than that of the periodontal ligament to reproduce an environment that was close to the clinical oral condition and the natural dentition as precisely as possible [21].

Using of implant placed at second molar region in distal extension case to support removable partial denture is an acceptable treatment modality. Many investigations mentioned that, the location of an implant underneath the denture base is closer to second molar, the better the occlusal support [22].

A drilling guide template has been used to facilitate the implant positioning in the accurate position. A clear drilling stent fabricated on a model with the ideal set-up ensures implant placement within the confines of the final denture base [23].

The drilling for the implant site was done by using the manufacture drills starting with the pilot drill, to make sure of the implant site parallism. Final drilling was done with the final drill to get full contact between the threads of the implant and the surrounding material of the model which will have the great effect on the load transfer from the implant to the supporting structures [24].

In this study, trough was made at the sites of the strain gauges for gaining deeper insight into the stress distribution at the implant—bone interface [25].

The instillation of strain gauges was done in prepared flat surfaces in the epoxy resin parallel to the long axis of the abutment tooth and the implant and perpendicular to the crest of the ridge buccally and lingually instead of placing the it directly on the root surface or implant surface because it is preferred to bond the strain gauge on completely flat surface to minimize the possibility of obtaining incremental apparent strain that result from mounting the strain gauge on curved surface [21,26].

Prosthetic appliances are exposed to a wide range of loading situations. The vertical (normal) maximum bite force of partially dentate patients wearing removable partial dentures has been reported to be in range 70–200 N [27].

Ascending vertical loads from 0 to 200 N were applied using the universal testing machine [28].

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Mean and SD of micro-strain measurements at implant and natural abutments under the three different designs.</th>
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<tbody>
<tr>
<td></td>
<td>Mean ± SD</td>
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<td></td>
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<tr>
<td>1. Cross arch (group I)</td>
<td>22.424 ± 18.851</td>
</tr>
<tr>
<td>2. Side plate (group II)</td>
<td>47.447 ± 44.343</td>
</tr>
<tr>
<td>3. Fixed (group III)</td>
<td>20.304 ± 12.774</td>
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<th>Table 2</th>
<th>Analysis of micro-strain measurements at the buccal and lingual sides of implant abutment.</th>
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<tr>
<td></td>
<td>Mean ± SD</td>
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<tr>
<td>LI</td>
<td></td>
</tr>
<tr>
<td>Group I</td>
<td>34.964 ± 19.878</td>
</tr>
<tr>
<td>Group II</td>
<td>107.895 ± 43.987</td>
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<tr>
<td>Group III</td>
<td>34.697 ± 12.513</td>
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<tr>
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<tr>
<td>Group I</td>
<td>34.059 ± 19.403</td>
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<tr>
<td>Group II</td>
<td>46.044 ± 16.287</td>
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<tr>
<td>Group III</td>
<td>20.304 ± 12.774</td>
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</tbody>
</table>
LLOYD digital loading device was used to deliver ascending load in this study. It is digital and easy to use. Besides, it offers high accuracy position measurement, rapid data acquisition and full personal computer integration [29].

For the accuracy of the results, an interval of at least 5 min between each reading was given to give a chance for heat dissipation from the strain gauge sensors [30].

Regarding to stresses recorded at buccal and lingual side of the implant, it was found that these stresses in case of side plate design were higher than stresses recorded in case of fixed and cross arch designs, and the stresses recorded at the same site in case of cross arch design are higher than stresses recorded in the case of fixed design.

This can be explained by easy dislodgment of side plate RPD which may increase the stresses around the implant abutment. These results were confirmed by many studies which concluded that although the advantage of side plate RPD of being more comfortable because it is less bulk in the mouth, it increased the stresses around the implant abutment [31,32].

The stresses recorded around the implant in case of fixed design were the least compared with other two designs. Rigid prostheses between a natural tooth and an implant may function very well over a long period of time, seemingly without any negative consequences for the initially established implant osseointegration [33,34].

On the contrary, some authors recommended the use of shock-absorbing element in the implant-tooth connected design to prevent the disuse atrophy or other damage to the natural tooth [35–37].

Regarding to stresses recorded at buccal and lingual side of the abutment tooth, it was found that these stresses in case of side plate design were also higher than stresses recorded in case of fixed and cross arch designs.

These results were supported by Aoda et al. [38] who made finite element analysis to retainer design for side plate removable dental prosthesis proved that the abutment tooth received high amount of load in side plate removable partial denture.

In the same context, many authors confirmed that unilateral distal extension R.P.D. exhibited considerable amount of displacement during function which increase stresses on tooth abutment [39,40].

<table>
<thead>
<tr>
<th>LI</th>
<th>Mean ± SD</th>
<th>ANOVA</th>
<th>TUKEY’S test</th>
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<tr>
<td>Group I</td>
<td>7.867 ± 3.851</td>
<td>138.971</td>
<td>&lt;0.001* Group I &amp; group II</td>
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<tr>
<td>Group II</td>
<td>18.831 ± 12.213</td>
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<tr>
<td>Group III</td>
<td>15.721 ± 7.318</td>
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<table>
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<tr>
<th>BU</th>
<th>Mean ± SD</th>
<th>ANOVA</th>
<th>TUKEY’S test</th>
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<tr>
<td>Group I</td>
<td>12.805 ± 6.283</td>
<td>30.096</td>
<td>&lt;0.001* Group I &amp; Group II</td>
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<tr>
<td>Group II</td>
<td>17.018 ± 10.769</td>
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<tr>
<td>Group III</td>
<td>13.018 ± 8.787</td>
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Graph 1. Histogram illustrates the micro-strain measurements under the three different designs.

Graph 2. Histogram illustrates the micro-strain measurements at the sites of the strain gauge sensors under the three different designs.
The total stresses recorded on both the implant and the abutment tooth in the three groups showed that the fixed design produced the least stresses followed by cross arch design and maximum stresses were recorded in side plate design.

Least stresses which were recorded in fixed design can be explained by the fact that the rigid connection allows better distribution of load between the implant and the abutment tooth [41,42].

Whereas tooth-implant connection is considered a viable treatment alternative, so long as non-rigid connection is used with caution as this increases stress on the prosthesis [42].

Lin and his co-workers concluded that the use of non-rigid connection might be more efficient in terms of compensation for the dissimilar mobility between the natural teeth and implant under axial loading forces. However, it should be used with caution as it breaks the stress transfer and increases the unfavorable stress values in prosthesis [43].

In clinical studies of patients, there are studies that consider tooth-implant connection as viable, achieving functional restorations. As for connection type, rigid connection is seen as the better option in order to avoid dental intrusion [42].

5. Conclusion

Within the limitation of this study the following could be concluded:

1. Maximum strain induced at tooth and implant abutments were in case of side plate design.
2. Distribution of micro-strain between the implant and tooth abutment in case of fixed restoration was better than distribution in case of the other two groups.

References
