Determination of strain around distal implants as abutments for partial and fixed implant-supported prostheses with posterior cantilever

Abstract

This study aimed to compare strain around implants used as abutments for removable partial dentures with wrought wires and fixed partial dentures with ball attachments and fixed dentures with posterior cantilever. An edentulous mandibular model was constructed using epoxy resin with four parallel implants in the area between the two mental foramina. Four strain gauges were attached to the buccal, lingual, mesial, and distal aspects of each implant. One fixed prosthesis with cantilever and two removable partial dentures were considered as prosthetic treatments. A vertical 500-N force was applied with 10-N intervals. The maximum strain in the fixed prosthesis was higher than that of the partial removable denture; in the removable denture with a wrought wire arm, it was higher than that in the denture with a ball attachment (P < 0.001). The lowest rate of strain was recorded on the mesial aspect (P < 0.05). However, the highest rate of strain was recorded on the lingual and distal aspects of the removable denture with a wrought wire in the buccal aspect and the removable prosthesis with the ball attachment on the buccal and lingual aspects (P < 0.05). Finally, despite minor differences in the maximum strain rate in each implant position, the differences were not statistically significant (P > 0.05). Partial removable denture with a ball attachment decreased strain more than that by the removable portal denture with a wrought wire arm. The worst type of prosthesis in terms of the overall strain rate was the fixed prosthesis with cantilever.

Key words: Fixed prosthesis, removable prosthesis, strain gauge

INTRODUCTION

Different treatment options with implants are available for edentulous patients. The use of implants in mandibular reconstruction has been associated with excellent results.[1] Although implant-supported prostheses are associated with numerous advantages, it is not possible to render such treatment to all patients without osseous grafts. Therefore, removable implant-supported prostheses are considered a favorable option.[2]

Previous studies have reported a high success rate with the use of four implants in the area between the mental foramina in edentulous patients.[3]
Excessive occlusal loads exerted due to inattention to the design of implant-supported prostheses are one of the most important factors for bone loss around implants and implant-supported prostheses.\[4\]

Bone biology studies have shown that when implants undergo excessive occlusal loads, significant deformation occurs at 2000–3000 microstrain levels at the peri-implant bone. When pathologic and excessive loads occur at microstrain levels of > 4000, the stress and strain exceed the bone tolerance threshold, finally resulting in microfractures at implant-bone interface.\[5\]

Some studies have suggested the use of implants as an abutment for removable partial dentures, with successful outcomes.\[6\] However, strain rate and distribution in the bone around the implant used as an abutment for the removable partial denture treatment are still unknown.

Different treatment plans are available for placing partial dentures with implant abutments in the anterior edentulous mandible: (1) use of cantilever fixed short-arch prostheses and (2) implant-supported overdentures.\[7\]

According to previous studies, cantilevers in implant-supported prostheses directly affect stress distribution around implants and stresses increase with an increase in the cantilever length.\[8\]

In the present study, the treatment plan consisted of the reconstruction of the anterior segment with implants with a fixed prosthesis and the use of partial dentures with different attachments for posterior areas to evaluate the distribution of stress in posterior implants for plans 2 and 3.

**MATERIALS AND METHODS**

**Preparation of the study model**

A patient with mandibular edentulism and moderate resorption of the mandibular ridge, who was a candidate for an implant-supported overdenture, was selected for this study.\[9\] An impression of the mandible was taken and poured with the Type III stone (Mold Stone, Pars Dandan, Iran). Special trays with acrylic spacers were fabricated for both jaws (Acropars 200, Eshtehard Industrial, Iran). The resulting cast was used to take an impression with a monophasic material (Panasil Monophasic Medium, Kettenbach, GmbH, Germany) and preserved for later use. A carbide bur (Tizkavan, Iran) was used to remove a layer, measuring approximately 2 mm, which is almost equal to the thickness of the mucosa in the mandible, from the surface of the stone case.\[10\] An impression was then made from the prepared cast using a monophasic material (Panasil Monophasic Medium, Kettenbach, GmbH, Germany) and poured with autopolymerized resin (POLYUROCK; Metalor technologies, Stuttgart, Switzerland). The resin’s flexural coefficient was 3000 MPa, which is similar to the trabecular bone.\[11\] Subsequently, using the first monophasic impression, Gingifast (Zhermack, A-silicone for gingival mask, Italy) was added to simulate the mucosa on the cast prepared using the Polyurock resin, and the final resin model was prepared.\[9\]

Four fixtures (Dentis, South Korea), measuring 12 mm in length and 3.7 mm in diameter, were placed at positions A, B, C, and D between the two mental foramina parallel to each other and perpendicular to the ridge crest, similar to the OD-4 plan of mandibular overdenture.\[9\] Stain gauges measuring 2 mm × 3 mm were used in the present study. Four strain gauges were selected for each implant and placed on the buccal, lingual, mesial, and distal aspects in a central position perpendicular to the surface. Cyanoacrylate glue (Grandil Co., Iran) was used to attach the strain gauges [Figure 1].

A try-in base was fabricated using VLC plates (Mega-Light Tray, Mega Dental, GmbH, Germany), measuring 2 mm in thickness to mount on the mandibular model.\[12\]

Wax occlusal rims (Cavex set up regular, Modeling wax, Netherlands) were placed on the try-in bases. The models were adjusted using bases and rims and mounted on an articulator (Hanau, Arcon, Germany) in a moderate Class I jaw relationship.\[9\] The analogs were connected, and the impressions were poured with Type III dental stone (Mold Stone, Pars Dandan, Iran). An alginate impression was taken from the maxillary model using a stock tray, and mounting was carried out on the articulator with the help of the existing base and rim. Straight abutments were then connected to the analogs. In the next stage, a 12-unit fixed prosthesis was fabricated on the cast and abutments [Figure 2].\[13\]
A resin index was prepared from this 12-unit bridge with the use of additional silicone impression material to ensure the similarity of contours and transfer the contours. Two 8-unit fixed prosthesis plans were designed and fabricated on the casts after preparing the silicone index so that the removable dentures could be fabricated on these two types of prosthesis with distal extension. These two types of prosthesis were fabricated by extension from the premolar area on one side to the premolar area; on the other side, their main difference was in their retention mechanism:

1. Prosthesis no. 1: Rests were placed on the mesial aspect of the first premolar teeth and the cingulum of the canine teeth, with guiding planes on the distal aspect of first premolar teeth. Two wrought wires were used as retention arms. Due to the round cross-section of wrought wires, this form of retention is more flexible than circular clasps [Figures 3 and 4][7]

2. Prosthesis no. 2: Two ball attachments were used distal to the first premolar teeth to fabricate this prosthesis. Ball abutments with a length of 4 mm manufactured by the South Korean company DIO were used in this investigation.

After fabricating two 8-unit fixed prostheses, one removable prosthesis with distal extension was fabricated on each of these designs. The first removable denture was fabricated and prepared by considering rests on the fixed prosthesis and placing two wrought wires. The second removable denture was fabricated without wrought wire retentive arms, using an extracoronal ball attachment system. The ball attachment was placed distal to the first premolar teeth on both sides. The prepared dentures were mounted on the chief model.[5] The strain gauge ends were connected to the signal conditioning amplifiers, which were monitored by MATLAB software.

**Connection to the apparatus simulating jaw movements**

A mechanical device that simulated the masticatory movements of the jaws was used to apply force. The device was able to apply 0–300-N force at 10-N intervals perpendicular to the occlusal surface of the teeth in an articulator, forcing the articulator to move laterally and protrusively with a range of 0–3 mm (GNATUS, NON-ARCON, BRAZIL).[5]

The device was adjusted to apply loads at 0–30-N range with 10-N intervals.[14] The ends of strain gauges were connected to the signal conditioning amplifiers, which were monitored by the MATLAB software.[5]

The strains were separately measured at different points in peri-implant bone and around the final prosthesis, using the following formula:

\[ \text{Stress} = \text{Strain} \times \text{Elasticity} \times (3000 \text{ MPa}) \]

(One-way ANOVA) as shown in Table 1 indicates that strain in the implants and different areas of the fixed prosthesis was significantly higher than the two other prostheses. The maximum strain in the removable partial denture with wrought wire was significantly higher than the removable partial prosthesis with a ball attachment \((P < 0.001)\).
Besides, Figures 5 and 6 compare the maximum strain rates in the three prosthesis types in terms of the surface and implant, respectively.

Table 2 presents the maximum strains measured on the four surfaces and in four implants. Figure 7 compares the maximum strain values on the four surfaces between the four implants, with no significant difference between different implants ($P > 0.05$).

However, the maximum strain on the mesial aspect was significantly lower than the lingual and distal aspects ($P = 0.004$ and $P = 0.01$, respectively).

Table 3 and Figure 8 presents the maximum strain values measured on four surfaces and four implants in the removable partial denture with wrought wire. Besides, Table 4 compares the maximum strain values between the four surfaces in four implants. The results showed no significant differences between the four different implants ($P > 0.05$). The maximum strains on the buccal aspect were significantly higher than the mesial aspects ($P = 0.001$ and $P = 0.007$, respectively) and significantly lower on the mesial aspect than the distal aspect ($P = 0.04$).

Table 4 presents the maximum strain values measured on four surfaces and four implants in the removable partial denture with the ball attachment. Also, Figure 9 compares the maximum strain values on four surfaces and in four implants. The results showed no significant differences between the different implants ($P > 0.05$). However, the maximum strain on the distal surface was significantly higher than the lingual surface ($P = 0.02$) and significantly lower on the mesial surface than the three other surfaces ($P = 0.02, P = 0.01$, and $P = 0.04$ for the buccal, lingual, and distal surfaces, respectively).

**DISCUSSION**

The present study aimed to determine and compare peri-implant strains in partial removable denture design with a wrought wire arm with a partial removable denture with ball attachment retention and cantilever prosthesis.

Based on the results, the overall strain was the lightest in the fixed prosthesis with cantilever and on the distal aspects of the two distal implants. In a study by Tashkandi *et al.*, the maximum strain was recorded in the cortical bone around the most distal implant, consistent with the present study. [15]
Koodaryan, et al.: Determination of strain around distal implants

Rodrigue et al. reported that the amount of stress transferred to the cortical bone might decrease with an increase in the number of implants and a decrease in the distance from the distal abutment. Considering the results of the studies above, it might be concluded that in fixed implant-supported prostheses with posterior cantilever, there is a higher strain in distal implants, which might be because when a force is applied to cantilever prostheses, the distal implant is subjected to higher tensile and shear forces.[16]

Clayton and Jaslow reported higher stresses and force on the abutment in wrought wire clasps than cast clasp bars.[17]

The flexibility of a wrought wire clasp marks it possible to place it in larger undercuts, which is one of the advantages of these clasps. However, based on the present and previous studies, this clasp can exert excessive forces on the abutment teeth, and the overall strain in this retainer design is significant, which might be attributed to factors such as incorrect bending and manipulation of this retentive arm.

The present study showed a significantly lower overall strain in the removable denture with a ball attachment than the two other designs; however, no significant differences were observed between the different implant surfaces.

Takahashi et al. evaluated the effects of three different types of attachment on maxillary implant-supported overdentures, reporting higher strain levels in the ball attachment design than the magnet and locator attachments.[18]

The present study showed a lower overall strain in the prosthesis with a ball attachment than removable prosthesis with a wrought wire retainer and fixed prostheses with posterior cantilever, which might be attributed to more favorable stress-breaking property and better distribution of stresses in this extracoronal retainer.

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**Table 3: The mean maximum stain values on different surfaces and in different implants in removable partial dentures with wrought wire**

| Surface    | Implant A | Implant B | Implant D | Implant E |
|------------|-----------|-----------|-----------|-----------|
| Buccal     | 87.2±6.4  | 89±6.7    | 72.7±5.1  | 66.5±7.6  |
| Lingual    |           |           | 96.2±16   | 63.7±4.6  |
| Mesial     | 62.5±3.5  | 63.7±2.6  |           | 64.6±3.4  |
| Distal     | 54.2±6.7  |           |           |           |

**Table 4: The mean maximum strain values on different surfaces and implants in the removable partial denture with the ball attachment**

| Surface    | Implant A | Implant B | Implant D | Implant E |
|------------|-----------|-----------|-----------|-----------|
| Buccal     | 58.7±3.1  | 60.7±4.5  | 44±2.8    |           |
| Lingual    |           |           | 62.5±3.5  | 57±10.7   |
| Mesial     | 57±10.7   | 52.7±8.1  | 52.2±5.7  | 54.2±6.7  |
| Distal     |           |           |           |           |

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**Figure 7**: Comparison of the maximum strain of different implants between different surfaces in the fixed prosthesis

**Figure 8**: Comparison of maximum strain values of different implants between different surfaces in removable partial denture with wrought wire
In all three prosthetic designs, the lowest strain was recorded on the mesial aspect. However, the highest strain in the fixed prosthesis was recorded on the lingual and distal aspects, in the removable partial denture with a wrought wire on the buccal aspect, and in the removable partial denture with a ball attachment on the buccal and lingual aspects. Finally, despite minor differences in the maximum strain in each implant, the difference was not significant on any prosthetic type.

In the present study, operators with similar skills and similar techniques were used. Besides, the conditions and factors selected for the study were similar for each area order study. The results showed different strain rates in terms of the prosthesis type, implant position, and the area evaluated.

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Conflicts of interest
There are no conflicts of interest.

REFERENCES

1. Gray D, Patel J. Implant-supported overdentures: Part 1. Br Dent J 2021;231:94-100.
2. Vogel RC. Implant overdentures: A new standard of care for edentulous patients current concepts and techniques. Compend Contin Educ Dent 2008;29:270-6.
3. Patel J, Gray D. Implant-supported overdentures: Part 2. Br Dent J 2021;231:169-75.
4. Sadowsky SJ. Occlusal overload with dental implants: A review. Int J Implant Dent 2019;5:29.
5. Hafezegoran A, Koodaryan R, Noorazar SG, Hajialilue-Bonab M, Hassanzadeh M, Yasamineh N. Evaluation of strain in mandibular denture-supporting area in three different occlusal schemes during jaw movements. J Dent Res Dent Clin Dent Prospects 2018;12:18-25.
6. Bereznicki T, Rai M. A technique to fabricate a new crown to an existing removable partial denture. Prim Dent J 2021;10:96-100.
7. Monteith BD. Management of loading forces on mandibular distal-extension prostheses. Part I: Evaluation of concepts for design. J Prosthet Dent 1984;52:673-81.
8. Zakaria A, Mustafa H. Duplicating the implant o-ring abutment retainer for using on tooth copy in mandibular implant-tooth partial overdenture: Radiographic evaluations. Eur J Dent 2012;4:45-55.
9. Misch CE. Contemporary Implant Dentistry. 1st ed. Saint Louis, Minnesota: Mosby; 1993.
10. Jacques LB, Moura MS, Suedam V, Souza EA, Rubo JH. Effect of cantilever length and framework alloy on the stress distribution of mandibular-cantilevered implant-supported prostheses. Clin Oral Implants Res 2009;20:737-41.
11. Oyar P, Durkan R, Deste G. The effect of the design of a mandibular implant-supported zirconia prosthesis on stress distribution. J Prosthet Dent 2021;125:502.e1-11.
12. Uchida H, Kobayashi K, Nagao M. Measurement in vivo of masticatory mucosal thickness with 20 MHz B-mode ultrasonic diagnostic equipment. J Dent Res 1989;68:95-100.
13. Morrow RM, Rudd KD, Rhoads JE. Dental Laboratory Procedures, Complete Dentures. 1st ed. St Louis: Mosby; 1986.
14. Zarb G, Hobkirk J, Eckert S, Jacob R. Prosthodontic Treatment for Edentulous Patients. 13th ed. Saint Lois, Minnesota: Elsevier; 2013.
15. Tashkandi EA, Lang BR, Edge MJ. Analysis of strain at selected bone sites of a cantilevered implant-supported prosthesis. J Prosthet Dent 1996;76:158-64.
16. Rodriguez AM, Aquilino SA, Lund PS, Ryther JS, Southard TE. Evaluation of strain at the terminal abutment site of a fixed mandibular implant prosthesis during cantilever loading. J Prosthodont 1993;2:93-102.
17. Clayton JA, Jaslow C. A measurement of clasp forces on teeth. J Prosthet Dent 1971;25:21-43.
18. Takahashi T, Gonda T, Maeda Y. Effect of attachment type on implant strain in maxillary implant overdentures: Comparison of ball, locator, and magnet attachments. Part I. Overdenture with palate. Int J Oral Maxillofac Implants 2017;32:1308-14.