Effect of Implant Position and Edentulous Span Length on Stresses Around Implants Assisting Claspless Distal Extension Partial Overdentures: An In Vitro Study.

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The aim of this in vitro study was to evaluate the effect of implant position and edentulous span length on stresses around implants assisting claspless distal extension partial overdentures. Four bilateral mandibular distal extension acrylic models were constructed. Two implants were inserted in the distal extension ridges parallel to each other and perpendicular to the ridges. Based on the implant position, models were categorized into two groups: Group I, mesial implants position and Group II, distal implant position. Each group was subdivided into 2 subgroups according to the length of edentulous span: Subgroup a, long span and Subgroup b, short span. Four claspless partial overdentures were fabricated on the models and retained to the implants with ball-and-socket attachments. Three strain gauges were cemented to the acrylic resin at buccal, lingual, and distal sides of each implant. Static unilateral vertical load of 60N was applied in the central fossae of the first molar, and peri-implant stresses were measured on loading and nonloading sides. Distal implant placements recorded significantly higher peri-implant stresses than did mesial implant placements. Long saddle recorded significantly higher stresses than did short saddle. The greatest peri-implant stresses were recorded with distal placement and long saddle at the loading side. At loading and nonloading sides, the mesial placement with a short saddle recorded the lowest strain. For mandibular distal extension partial overdentures, a mesially placed implant combined with short saddle may be preferable to a distally placed implant combined with long saddle, as the former was associated with reduced peri-implant stresses.

Key Words: implant position, span length, stresses, implants and distal extension partial overdentures

INTRODUCTION

The difference in resiliency between the mucosa and periodontal ligament of abutment teeth usually complicate the loading of the mandibular Kennedy class I distal extension removable partial dentures.[1] The lack of distal dental support results in transmission of vertical, horizontal, and torsional forces to supporting tissues during mastication[2,3] with subsequent adverse changes in both abutment teeth and edentulous areas.[4] In addition, conventional removable partial dentures (RPDs) have several problems related to the presence of clasps, such as minimal retention and stability, unesthetic appearance, and poor patient satisfaction.[5]

Traditional prosthodontic management of partially edentulous patients has expanded with the introduction of osseointegrated implants.[6] The use of implants to support and retain RPDs—implant-assisted distal extension partial overdentures—has been reported to minimize RPD dislodgement, provide additional retention and stability, and improve patient satisfaction in a cost-effective manner.[7,8] Moreover, implant-assisted distal extension partial overdentures provide a stable and durable occlusion, prevent alveolar bone resorption beneath the RPD base,[4] reduce stress on the natural abutment teeth,[1] and reduce the need of unesthetic buccal retentive arm clasps.[9–11] Implant-assisted distal extension partial overdentures also convert Kennedy class I to tooth-implant supported and retained prosthesis (Kennedy class III),[7,12,13] Such prostheses can be retained to the implants with different unsplinted anchors such as ball, Locator, and magnetic attachments.[1]

The implants for implant-assisted distal extension partial overdentures may be positioned distally to provide maximal support and stability and to convert the Kennedy Class I RPDs to Kennedy Class III, which is favorable from a biomechanical point of view.[14,15] However, limited height of the posterior mandibular ridge may restrict implant placement to a more mesial location (distal to the remaining abutment teeth).[2]

Controversy exists in the literature regarding the best implant location that reduces stresses to the supporting structures for implant-assisted distal extension partial overdentures.[16] Hegazy et al[17] compared strains around abutments and implants when these implants are placed in the first premolar (mesial implant placement) or second molar (distal implant placement) areas for implant-assisted distal extension partial overdentures. They found significant higher stresses around the implants and the abutments with mesial implant

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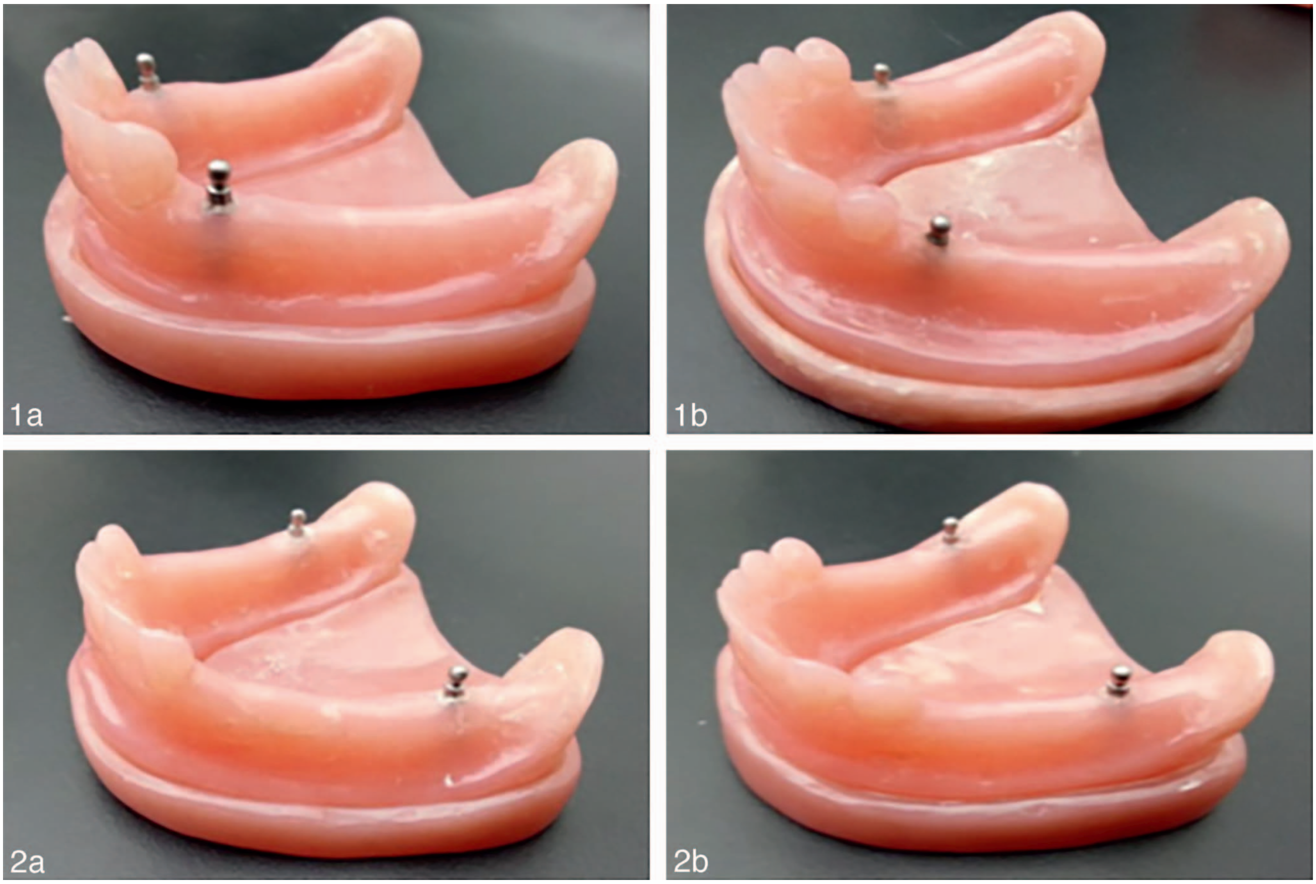


Figures 1 and 2. Figure 1. Group I (mesial implants). (a) Subgroup Ia (long span). (b) Subgroup Ib (short span). **Figure 2.** Group II (distal implants). (a) Subgroup IIa (long span). (b) Subgroup IIb (short span).

placement compared to distal implant location. Cunha et al[2] concluded that placement of the implant in the mesial region near the abutment tooth positively influenced the distribution of stresses on the implant and abutment teeth compared to implants placed in the distal region.

Stresses transmitted by implant-assisted distal extension partial overdentures around abutment teeth[1,18] and implants[19–21] were evaluated using in vitro studies. However, the effect of implant location and edentulous span length on stresses around implants assisting such prostheses were not concerns. Therefore, the aim of this in vitro study was to evaluate, by means of strain gauge analysis, the effect of implant position and edentulous span length on stresses around implants assisting claspless distal extension partial overdentures.

MATERIALS AND METHODS

Test model fabrication

Four acrylic resin models were fabricated to represent mandibular Kennedy Class I RPD. Two models had 6 anterior teeth remaining and two models had 8 remaining teeth (6 anterior teeth and first premolars). For each model, the residual ridge was covered with a 2-mm thickness of self-cure silicone layer (Permafix Kohler, Medizintechnik, Bodenseeallee, GmbH, Germany) to simulate the edentulous ridge mucosa.

For each model, two 3.7 × 13 mm laboratory implants (Zimmer, Inc, TSV, Carlsbad, Calif) were placed bilaterally in the distal extension ridges using a guide template. The implants were inserted parallel to each other and at right angle to the ridge using a dental surveyor (Ney Surveyor, JM Ney Co, Hartford, Conn) and fixed to the casts using a cement to simulate osseointegration (RelyX Unicem Self-Adhesive, 3M ESPE, St Paul, Minn). The models were categorized into 2 groups according to implant location:

1. Group I (Figure 1): The implants were placed mesially. This group was divided into 2 subgroups according to span length: (1) Subgroup Ia (long span): the implants were placed in the first premolar position of the acrylic model with remaining 6 anterior teeth (Figure 1a); (2) Subgroup Ib (short span): the implants were placed in the second premolar position of the acrylic model with remaining 6 anterior teeth and first premolars (Figure 1b).

2. Group II (Figure 2): the implants were placed distally. This group was divided into 2 subgroups according to span length: (1) Subgroup IIa (long span): the implants were placed in the second molar position of the acrylic model with remaining 6 anterior teeth (Figure 2a); (2) Subgroup IIb (short span): the implants were placed in the second molar position of the

Figure 3. Removable partial denture design.

acrylic model with remaining 6 anterior teeth and first premolars (Figure 2b).

Every experimental model was duplicated as a refractory cast. Wax patterns for the metallic frameworks were adapted to the casts. The following components of the RPDs were used (Figure 3): (1) lingual bar major connector, joining the bilateral meshwork RPD denture bases); and (2) canine rests, connected to the lingual bar with minor connectors to act as indirect retainer. No clasps were used. Wax patterns were cast into a cobalt-chrome alloy. Forty experimental RPDs (each experimental RPD consisted of cobalt-chrome framework, acrylic resin denture base and artificial teeth) were then constructed (10 RPDs for each group). The denture bases and artificial teeth were duplicated for all RPDs using a polyvinylsioxane silicone mold.

Distal extension partial overdentures were retained to the implants using ball-socket attachments (Zimmer Inc, TSV, Carlsbad, Calif). The acrylic resin in the fitting surface of the RPDs was removed around the ball abutments to ensure that retention is gained from the attachment only.[1]

Strain gauge installation

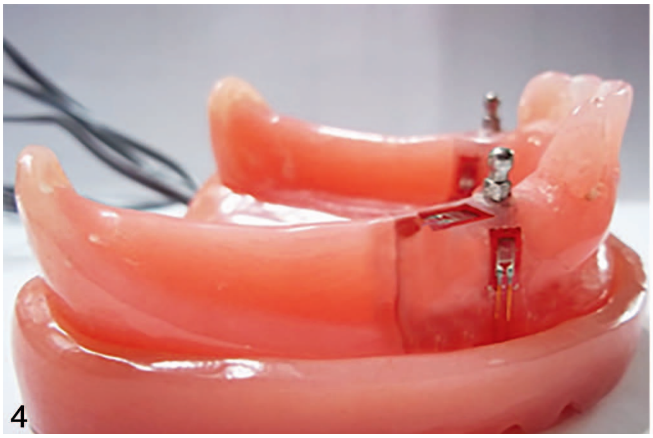
The silicone mucosa was removed around implants to allow strain gauge cementation to the acrylic resin. These areas were prepared flat, leaving only 2-mm thickness of the acrylic resin covering each implant.[22] Three linear strain gauges (FLA-2-11-1L1M2R; Kyowa Electronic Instruments Co, Ltd, Tokyo, Japan; resistance 119.8 ± 0.5% Ω; gauge length: 2 mm; gauge factor: 2.11 ± 1.0%) were cemented at buccal, lingual, and distal surfaces of each implant at the loading and nonloading sides using an adhesive provided by the manufacturer (Figure 4). The lead wires of the gauges were fixed to the models, and the terminals of the 6 gauge wires were connected to a quarter bridge circuit of a digital strain meter (Model 8692, Tinsely Precision Instruments, Surrey, UK) that converts electric output into microstrain using software (Kyowa PCD-300A, Kyowa Electronic Industries Ltd, Tokyo, Japan).

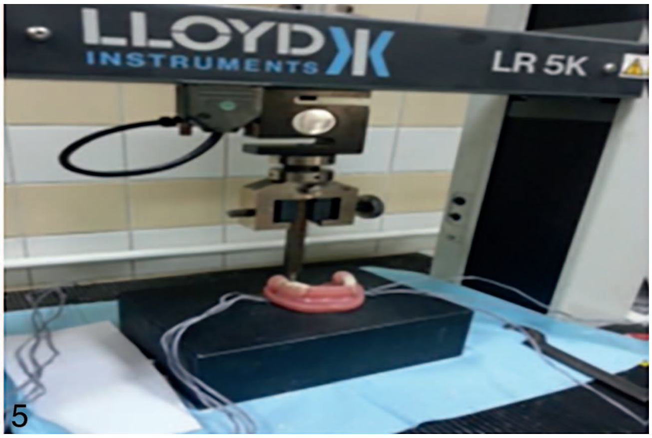
Strain gauge calibration

Before the experiment, an acyclic load ranging from 10 to 60N was applied 5 times in 10-N steps on the occlusal surface of mandibular RPDs using a loading device (Lloyd LRX, Lloyd Instruments Ltd, Fareham, Hampshire, UK) to assess the repeatability of force measurements and the linearity of the gauges.[1,23]

Strain gauge measurements

Digital loading device (Lloyd LRX, Lloyd Instruments) was used to apply 60N unilateral vertical static compressive load in the central fossae of the first molar on right side at a constant rate (crosshead speed) of 0.5 mm/min[22] (Figure 5). The central fossa of the first molar was notched with a rounded bur to prevent





Figures 4 and 5. Figure 4. Strain gauge positions. **Figure 5.** Unilateral vertical loading.

slippage of the loading pin and to ensure reproducibility.[24] For each experimental overdenture, the load was repeated 10 times with at least 5-minute rest periods to allow for heat dissipation, and the mean microstrains were recorded. Microstrains were then converted to stresses using the equation "Stress/strain = modulus of elasticity," where the modulus of elasticity for acrylic resin is 3.2. The mean recorded stresses from buccal, lingual, and distal strain gauges were subjected to statistical analysis.

Statistical analysis

The SPSS statistical package for social science V22 (SPSS Inc, Chicago, Ill) was used for data analysis. The data were nonparametric and violated the normal distribution. To compare stresses between subgroups, the Kruskal-Wallis test was used. If significant differences were detected, the Mann-Whitney test was used for pairwise comparisons. To compare stresses between implant positions, span lengths, and loading sides, the Mann-Whitney test was used. *P* value is significant at $<.05$.

RESULTS

Negative values represent compressive stresses, and positive values represent tensile stresses. Comparison of peri-implant stresses between groups, regardless of the length of the edentulous span, is presented in Table 1. The distal implant position recorded significant higher peri-implant stresses than did the mesial implant position at loading and nonloading sides (Mann-Whitney test, $P = .00$). Comparison of stresses between long and short saddles, regardless the group, is presented in Table 2. Long saddle recorded significantly higher peri-implant stresses than did short saddle at loading ($P = .047$) and nonloading sides ($P = .045$).

Comparisons of peri-implant stresses between subgroups at loading and nonloading sides are presented in Table 3. At the loading side, there was a significant difference among subgroups (Kruskal-Wallis test, $P = .004$). Subgroup IIa (distal implants with long saddle) recorded the greatest peri-implant stresses, and Subgroup Ib (mesial implants with short saddle) recorded the lowest stresses. At the nonloading side, there was a significant difference between subgroups (Kruskal -Wallis test, $P = .001$). Subgroup IIb (distal implants with short saddle) recorded the greatest peri-implant stresses, and the Subgroup Ib (mesial implants with short saddle) recorded the lowest stresses. Multiple comparisons between subgroups are also presented in Table 3.

Comparison of peri-implant stresses between loading sides for all subgroups is also presented in Table 3. With exception of Subgroup Ia (mesial implants with long saddle), there was a significant difference in peri-implant stresses between loading and nonloading sides (Mann-Whitney test, $P < .05$). The loading side recorded significant higher stresses than did the non-loading side.

DISCUSSION

The results reported in this study must be considered from a biomechanical point of view since the models represent a simplification of the investigated structures. Moreover, this study considers only one prosthetic design (claspless RPD) and does not take into account the numerous designs that could be adopted, including clasps and indirect retainers. Another limitation was that controlled loading conditions only were evaluated (namely, unilateral loading) and only one vertical

TABLE 1

Comparison of peri-implant stresses between mesial and distal implant positions at loading and nonloading sides†

	Right Side (Loading Side)	Left Side (Nonloading Side)
Group I (mesial implants)		
M	−20.0000	−10.0000
Min	−215.00	−20.00
Max	265.00	5.00
Group II (distal implants)		
M	47.5000	−22.5000
Min	.00	−75.00
Max	260.00	30.00
Mann-Whitney test (*P* value)	.00*	.00*

*Significant at 5% level of significance.

†M indicates median; min, minimum; max, maximum

Table 2

Comparison of peri-implant stresses between long and short saddles at loading and nonloading sides†

	Right Side (Loading Side)	Left Side (Nonloading Side)
Long saddle		
M	32.5000	−15.0000
Min	−215.00	−55.00
Max	265.00	.00
Short saddle		
M	15.0000	−10.0000
Min	−20.00	−75.00
Max	260.00	30.00
Mann-Whitney test (*P* value)	.047*	.045*

*Significant at 5% level of significance.
†M indicates median; min, minimum; max, maximum.

point of load application was used. However, masticatory forces are usually complex and multidirectional. It should also be emphasized that the aim of the study was not to report the absolute values of stress but to compare the stress levels in different implant positions.[22]

Strain gauge analysis was used to evaluate stresses around implants assisting distal extension partial overdenture[19–21] as it overcomes many shortcomings of other methods.[25] Stafford and Glantz[26] recommended the use of strain gauges for measuring strains due to the small dimension. They added that this method provides a quantitative information about the measured strain.

In this study, acrylic resin was used for construction of the model as it has the modulus of elasticity, similar to compact bone.[27] To measure stresses transmitted by the prosthesis to the bone through the implants, strain gauges were bonded to the surface of the acrylic resin around the implants after removing the silicone mucosal simulation. It was assumed that stress measured directly on the bone surface could be representative of stress that is introduced to the bone around implants.[28–29]

Three strain gauges were attached to buccal, lingual, and distal sides of the implants, but no strain gauges were attached to the mesial surface due to the presence of acrylic teeth mesial to the implants in Group I. Similar strain gauge positions were also recommended in other studies[1,17,19] to measure the stresses around the abutments of implant-assisted distal extension partial overdentures. This distribution gives an accurate and conclusive measurement of strains generated around implants.

In this study a load of 60N was applied to the central fossae of first molars where the occlusal force tends to be concentrated and the RPD would move the most.[28] This amount of biting force was used to represent moderate level of chewing force for implant-retained overdenture patients.[1,28,30] To simplify the study and exclude confounding variables, all measurements in this study were conducted with one point vertical static loading opposing to the first molar. The first molar was chosen because maximum occlusal forces are often exerted in this region, where there is maximum contraction of the elevator muscles.[31]

The application of dental implants to restore missing teeth of partially edentulous patients is going to be a predictable technique.[32] The choice of position, number, diameter, and length of dental implants used to support prostheses is an important condition to evenly distribute the masticatory load.[33] Moreover, it is important to select the retention mechanism that transfers minimal stresses to the peri-implant region under simulated masticatory load[34,35] to minimize peri-implant bone resorption and obtain long-term success.

For distal extension partial overdenture, Mijiritsky et al[10] stated that implant placement should be based on the ideal biomechanical location for the ball attachment. Brudvik[5] stated that molar (distal) and canine (mesial) positions are the most adequate positions for implants used to assist distal extension partial overdentures. Implant insertion on the molar region is preferred from a biomechanical point of view as it converts Kennedy class I to class III.[7,12,13] When lateral incisors are the

Table 3

Comparison of peri-implant stresses between subgroups at loading and nonloading sides†

	Right Side (Loading Side)	Left Side (Nonloading Side)	Mann-Whitney Test (*P* value)
Subgroup Ia (mesial implants with long saddle)			
M	−60.00 a	−10.00 a	.12
Min	−215.00	−20.00	
Max	265.00	.00	
Subgroup Ib (mesial implants with short saddle)			
M	−20.00 b	−10.00 ab	.048*
Min	−20.00	−10.00	
Max	50.00	5.00	
Subgroup IIa (distal implants with long saddle)			
M	70.00 c	−15.00 ac	.00*
Min	5.00	−55.00	
Max	90.00	−10.00	
Subgroup IIb (distal implants with short saddle)			
M	35.00 abc	−30.00 abd	.00*
Min	.00	−75.00	
Max	260.00	30.00	
Kruskal-Wallis test *P* value	.004*	.001*	

*Significant at 5% level of significance; different lowercase letters indicating significant differences among subgroups (Mann-Whitney test, $P < .05$).
†M indicates median; min, minimum; max, maximum.

only present abutments, insertion of the implants in the canine areas can provide support and retention, eliminate the use of unesthetic retentive clasps, and prevent unfavorable horizontal forces that may damage the abutment periodontium.[16]

One goal of the clinician should be to provide the most favorable delivery of forces to the implant through prosthesis design.[28] Still to be determined is the ideal position of the implants for distal extension partial overdentures that will reduce the peri-implant stresses and consequently marginal bone loss. In clinical situations, the increased stresses on the unsplinted implants may result in increased magnitude of micromotions. If these micromotions exceed 100 μm, it may result in greater bone turnover.[36] The increased stress values at the bone-implant interface are not desirable since they may cause bone loss through the induction of bone microdamage and may lead to failure of osseointegration.[37,38]

From the results of this study, regardless of saddle length, the distal implant position recorded significant higher peri-implant stresses than did the mesial implant position. The reduced stress around mesially placed implants may be due to the RPD denture base's tendency to rotate around the implants (which act as a fulcrum) during load application. This fulcrum is created by the ball-and-socket design of the used attachment, which has no intervening space. Therefore, this attachment acts as a positive occlusal stopper, thus tending to rotate the RPD rather than intrude and cause the metal framework (lingual bar) to move away from the tissues anteriorly due to absence of clasp assemblies on the abutment teeth. This rotation results in a decrease of transmitted stresses around mesial implants. From these results, it may be clinically advantageous to place the implants assisting distal extension partial overdentures in a mesial position (adjacent to abutment teeth) to protect peri-implant marginal bone from excessive stresses that may lead to bone microdamage and resorption.[37,38]

The reduced stresses around mesially placed implants agree with the findings of Cunha et al,[2] who concluded that locating the implant near the abutment tooth positively influenced the distribution of stresses, thereby improving prosthesis stability in the vertical plane. However, RPD rotation is less likely to occur in case of distally placed implants; consequently, more load is transferred to the implants in a vertical direction. The presence of the implants in a distal position diminishes RPD intrusion and minimizes the movement of the prosthetic seat in the vertical direction.[2] In agreement with this finding, Elsyad et al[4] reported that when implants were placed at first molar areas to support distal extension partial overdentures with ball-and-socket attachment, the posterior ridge was protected from excessive loading as most of load is transmitted vertically to the implants, thereby reducing posterior mandibular ridge resorption. The authors attributed the reduced resorption rates to the direct metal frame contact with healing abutments, which provide effective support and prevent the potential for RPD rotation. In contrast, Hegazy et al[17] noted significant increases in the stresses induced around mesially positioned implants for retention of mandibular distal extension partial overdentures (with remaining 6 anterior teeth) compared to distally placed implants.

Regardless of implant position, the long saddle recorded significant higher stresses than did the short saddle. This finding is in agreement with Patrnogic et al,[39] who reported high stress levels on the primary abutments when the long saddle was used. The longer the edentulous span, the longer the RPD denture base and the greater the leverage force transition will occur. In line with this finding, Shahmiri[40] reported that during unilateral loading of implant-assisted distal extension partial overdentures, the curvature of the dental arch can result in vertical and lateral displacement of the prosthesis. Therefore, an off-axis lever is created, which may cause twisting of the metal structure; as the length of the RPD denture base increases, the length of the lever arm also increases, as does the twisting effect. Twisting the rigid major connector may create compressive microstrains on the metal surface. These microstrains may be transmitted around the implants because the attachment usually provides adequate resistance to displacement.[38] As the length of the denture base increases, the peri-implant stresses increase. Therefore, in a clinical situation, short RPD denture saddles are recommended or even omitting placement of second molar teeth in cases of long span implant-assisted distal extension partial overdentures to preserve peri-implant marginal bone.

The peri-implant stresses at the loading side were significantly higher than stresses at nonloading sides. This is in agreement with Tokuhisa et al,[28] who reported that implant stress values at the nonloaded side were much lower than stress values at the loaded side. Therefore, it may be advantageous from a clinical point of view to balance the occlusion when implant-assisted distal extension partial overdentures were used. This distributes the pressure on working and balancing sides, avoiding concentration of peri-implant stresses on the loading side, which may increase bone remodeling and resorption.

Conclusions

Within the limitations of this in vitro strain gauge analysis, the following conclusions could be drawn:

- Distal implant position for distal extension partial overdentures recorded significantly higher peri-implant stresses than did the mesial implant position.
- Long saddle of implant-assisted distal extension partial overdentures recorded significantly higher peri-implant stresses than did the short saddle.
- Distal implant position with the long saddle recorded the greatest peri-implant stresses, and the mesial implant position with the short saddle recorded the lowest stresses.

Abbreviation

RPD: removable partial dentures

Note

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