

Stress Analysis of Two Attachment Types for Implant-Supported Overdentures in Hemimandibulectomy Cases

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Abstract

Objective: The purpose of this study was to compare two attachment types for implant-supported overdentures in hemimandibulectomy cases using strain gauge technology.

Materials and Methods: Three titanium internal hex implants were inserted in a simulated cast of a hemimandibulectomy case resected from the right side. Two overdenture designs were constructed (ball and socket design and OT-bar-clip design). Five strain gauges were adhered in relation to the three implants. Vertical static load was applied in the area of the first molar on both sides and lingual to the lower anterior teeth. Data were analyzed by t-test and one-way ANOVA followed by Tukey's *post hoc* test at a significance level of $\alpha = 0.05$.

Results: The statistical analysis revealed significant differences between the two attachment types; labial and distal to the anterior implant, labial to the middle implant and labial and distal to the posterior implant.

Conclusion: OT-bar-clip attachment generates higher stresses on implant-supported overdentures in hemimandibulectomy cases than ball and socket attachment.

Keywords: *Stress Analysis; Implant; Overdentures; Hemimandibulectomy*

Introduction

The mandible is one of the strongest and largest bone of the human face, not only it forms the lower jaw but its mobility is the single largest determining factor in dental occlusion that serves the functions of speech, mastication and deglutition. This unique bone is joined to the cranium by two joints that need to work in coordination for efficient mandibular movements [1,2]. The mandible is also the most common site for intraoral tumors which often requires the resection of large portions of the mandible [3].

Management of these malignant tumors associated with the tongue, floor of the mouth, the mandible and the adjacent structures represents a difficult challenge for the surgeon, radiation oncologist and prosthodontist relative to both control of the primary disease and rehabilitation after treatment [1].

After mandibular resection, some disabilities may arise including; impaired speech articulation, difficulty in swallowing, problems with mastication, severe cosmetic disfigurement, compromised control of salivary secretion due to radiation therapy and deviation of the mandible during functional movements [1].

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This deviation is medially and superiorly [4], it is due to uncompensated influence of contralateral musculature particularly the internal pterygoid muscle, and pulls from the contraction of cicatricial tissues on the resected side [5,6]. The contraction of mentalis, buccinators or mylohyoid muscles could lift the denture off the soft tissue. As a consequence, teeth may touch during speech and elicit clicking noises [7]. The degree of deviation depends on many factors; location and extent of osseous and soft tissue resection, method of surgical site closure, degree of nerve involvement, degree of impaired tongue function, use of adjuvant procedures like radiation therapy, presence and condition of the remaining natural teeth, and timing of prosthodontic treatment [4,8,9]. This deviation increases upon opening the mouth leading to angular pathway of opening and closing [10].

Cantor and Curtis [11], developed a classification for edentulous and partially edentulous arches which includes; Class I, mandibular resection involving alveolar defect with preservation of mandibular continuity. Class II, resection defects involve loss of mandibular continuity distal to the canine area. Class III, resection defects involving loss up to the mandibular midline region. Class IV, resection defects involving the lateral aspect of the midline but are augmented to maintain pseudoarticulation of bone and soft tissues in the region of the ascending ramus. Class V, resection defects involving the symphysis and para-symphysis region only, augmented to preserve bilateral temporomandibular articulation. Class VI, similar to class V except that the mandibular continuity is not restored.

In these mandibular discontinuity defects, complete dentures are only for esthetics, while mastication becomes difficult due to compromised denture bearing surfaces, angular pathway of closure and abnormal jaw relationship, deviation of the mandible, impaired motor and sensory innervation of the remaining tissues and most importantly, compromised tongue function. Implant retained overlay prostheses provide support for these cases derived from residual denture bearing surfaces, while retention and stability are provided by the implants which is more than sufficient to allow effective mastication without the need for the tongue to control the denture as in complete dentures [1].

Ball and bar attachments are two main retainer systems for implant-supported/retained overdentures. The resilient ball type of attachment helps to transfer the stresses in a more favorable manner to the posterior mandibular residual ridge [12], and provides better load distribution between the implant and the ridge than the bar-clip attachment system [13].

Strain gauges were used to evaluate occlusal force values of mandibulectomy subjects with reconstructed mandibles [14]. Additionally, it has been used to measure and compare forces and moments acting on implant abutments of various designs of implant-supported overdentures [15].

Although many case reports have been made for the prosthetic treatment of hemimandibulectomy patients [16,17], very few studies have investigated using implants and precision attachments for treatment of hemimandibulectomy patients.

The aim of this study was to evaluate stresses generated by two types of attachment for implant-supported overdentures in hemimandibulectomy cases using strain gauge stress analysis.

Materials and Methods

A rubber mold for completely edentulous mandible used for educational purposes which accurately replicates the anatomic features of the supporting structures was used and poured to obtain a stone cast (Figure 1). Part of the ridge was removed from the right side (starting from the premolar area till the area beyond the last molar) to represent hemi-mandibulectomy edentulous case. Duplication of the cast was made and poured with transparent heat cured acrylic resin which was then finished and polished. Simulation of the mucosa covering the residual ridge was done using a chemically cured silicone resilient material (Soft liner, Promedica, D-24537 Neumunster, Germany) (Figure 2).

The model was prepared to receive three titanium internal hex screw type implants (TUT, Egyptian Co. for Dental Implants, Egypt) (13 mm in length and 3.9 mm in diameter), on the intact side in a tripod manner. The anterior implant was apart from the middle one by 15 mm. while the distance between the middle and the posterior implants was 7 mm (Figure 3), implant transfers were inserted, alginate

impression was taken, analogues were inserted in the impression then tightening of the transfers was done and then the assembly was boxed and poured in a dental stone to construct a working cast for the fabrication of the two overdenture designs.



Figure 1: The stone cast before modification.

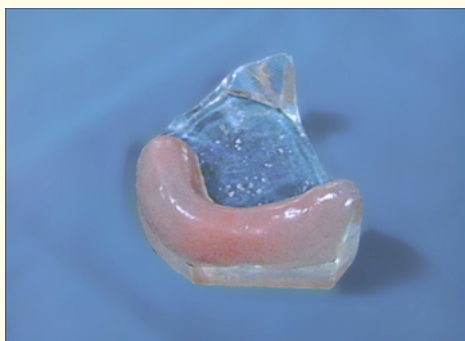


Figure 2: The acrylic resin model with silicone resilient material covering the residual ridge.

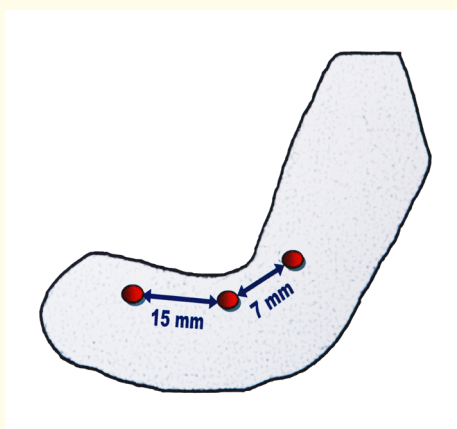


Figure 3: Diagrammatic representation of the implants' position.

On the working cast, fabrication of an overdenture retained by OT- bar-clip was done with the bar used in its resilient form and the OT-bar-clip attachment extended 7 mm from its both terminals, all the measurements were taken from this design then the bar assembly was removed from the acrylic denture and replaced with the ball and socket attachment by direct pick up technique to record the same records of the OT- bar-clip attachment and to exclude any variations in the overdenture acrylic design.

The acrylic cast was modified by reducing the acrylic around each implant by thinning it in all directions around the implant leaving only 1 mm thickness of acrylic resin. Five strain gauges (KFG-1-120-11, Kyowa Electronic instruments Co., Japan. Specifications: grid: length 1 mm, width 1.1 mm and base: length 4.8 mm, width 2.4 mm, nominal resistance 129 ohm) were then bonded on five selected sites around the three implants as follows:

- Distal to the anterior implant (D.A.)-Labial to the anterior implant (L.A.)
- Labial to the middle implant (D.A.)
- Distal to the posterior implant (D.P.)- Labial to the posterior implant (L.P.)

The strain gauges were protected with an insulating coat (11-Current study-1A Moist Proofing wax, Kyowa Electronic Instruments Co., Japan) for long term protection against moisture.

The point of load application was notched with the same diamond stone on the two designs on the occlusal surface of the first molar on the intact side, on the first molar of the resected side and lingual to the midline between the lower anterior teeth and 99 Newton static loads was applied five times for each side, the readings were delivered by a digital strainmeter (Digital Strainmeter, Tc-31k, Tokyo, Sokki Ken Kyuio Co., Ltd) the arithmetic mean and standard deviation were calculated, tabulated and statistically analyzed and divided into 3 groups:

- G1: loading anteriorly which was further divided into 2 groups:
 - G1 A: loading anteriorly on the OT bar-clip overdenture.
 - G1 B: loading anteriorly on the Ball-socket overdenture.
- G2: loading on the intact side which was further divided into 2 groups:
 - G2 A: loading the intact side on the OT bar-clip overdenture.
 - G2 B: loading the intact side on the Ball-socket overdenture.
- G3: loading on the resected side which was further divided into 2 groups:
 - G3 A: loading the resected side on the OT bar-clip overdenture.
 - G3 B: loading the resected side on the Ball-socket overdenture.

Statistical analysis

Means and standard deviations were calculated for generated strains. Data were analyzed by t-test and one-way ANOVA followed by Tukey's *post hoc* test. All statistical analyses were conducted at a significance level of $\alpha = 0.05$.

Results

Results for the OT-bar-clip attachment type showed greater microstrains on both labial surfaces at the anterior and posterior implants when the load was applied at the anterior point (G1). However, when load was applied on the intact and resected sides, greater microstrains were recorded on the labial surface of the middle implant.

On the other hand, the ball-socket attachment showed greater microstrains on the labial surface of the middle implant when load was applied on the anterior region of the overdenture and also on the intact and resected sides.

The statistical comparison between the two designs using t-test for independent samples illustrated significant differences in stress generated when load was applied anteriorly ($P < 0.05$) (labial to the anterior implant, and distal and labial to the posterior implant).

When load was applied on the intact side (G2), the statistical comparison between the two attachments using t-test for independent samples illustrated a number of significant differences ($P < 0.05$) with greater stresses generated by the OT-bar-clip attachment (labial to the anterior implant, labial to the middle implant and distal to the posterior implant).

Stresses generated when load was applied on the resected side (G3) illustrated no significant differences between the two implant overdenture designs.

The above mentioned results are illustrated in Table 1.

| Gauge location | Group1 (Anterior side) | | Group2 (Intact side) | | Group3 (Resected side) | |
|----------------|---------------------------|-------------|-------------------------|-------------|---------------------------|-------------|
| | (G1 A) | (G1 B) | (G2 A) | (G2 B) | (G3 A) | (G3 B) |
| | OT-bar-clip | Ball-socket | OT-bar-clip | Ball-socket | OT-bar-clip | Ball-socket |
| D.A. | 6.0 ± 0.20 | 7.6 ± 0.96 | 2.8 ± 0.13 | 4.8 ± 0.49 | 0.3 ± 0.01 | 1.0 ± 0.10 |
| L.A. | 47.0 ± 1.00 | 22.8 ± 0.11 | 40.0 ± 0.65 | 12.0 ± 0.13 | 8.0 ± 0.19 | 6.8 ± 0.31 |
| L.M. | 28.4 ± 0.39 | 28.8 ± 0.13 | 121.6 ± 1.90 | 66.2 ± 2.60 | 18.0 ± 0.23 | 17.4 ± 0.26 |
| D.P. | 11.8 ± 0.10 | 7.0 ± 0.18 | 25.2 ± 0.57 | 7.6 ± 0.20 | 6.2 ± 0.84 | 5.8 ± 0.13 |
| L.P. | 51.4 ± 0.57 | 10.2 ± 0.62 | 8.4 ± 0.77 | 18.0 ± 0.11 | 3.4 ± 0.25 | 3.2 ± 0.13 |

Table 1: Microstrains recorded when the load was applied on the anterior, intact and resected sides from OT-bar-clip attachment and ball-socket attachment.

Values are means ± standard deviations.

D.A.: Strain gauge distal to the anterior implant.

L.A.: Strain gauge labial to the anterior implant.

L.M.: Strain gauge labial to the middle implant.

D.P.: Strain gauge distal to the posterior implant.

L.P.: Strain gauge labial to the posterior implant.

Discussion

Implant-prosthetic rehabilitation in oncologic resected patients represents the best prosthetic solution as it provides many advantages compared to traditional rehabilitative solution, including a greater masticatory comfort and psychological acceptance. In particular, it provides an improvement of the functions of the mouth and of the prosthesis stability. And although the tissue reconstruction by means of revascularized free flaps is successful; it is characterized by thickness and volumes that would limit the stability and the retention of traditional removable prostheses. It is also important to mention that the success of prosthetic rehabilitation in cancer patients is influenced not only by the hard tissue but also by the soft tissues which are often undergo repeated surgery and radiotherapy which render them less elastic and inadequate to traditional prosthetic solutions [18].

Bone, like any other material, will be damaged if the stresses and strains become too high at a particular point in the material. It is important to know what stresses and strains develop at the exact region where the implant surface comes into contact with the surrounding bone or other tissues, as the cells of blood and bone near a loaded implant will also be loaded and could be affected by the local stress-strain fields [19].

Both tensile and compressive axial loads can occur on implants, while the axial loading and bending moments can exist on implants with long cantilevers. Therefore, the validation of the analytic models would be useful to allow for good evaluation and predictions of the amount of load on implants [19].

As the resiliency of the soft tissues and human mandible varies from person to person depending on the amount of available bone and soft tissue, so the acrylic model which remained constant throughout the experiment controlled this variability [15].

The load applied was considered to be static, although the actual biting force is dynamic. Static loads were considered to be sufficient for the purpose of this study as they give good representation of the behavior of the appliance when subjected to oral dynamic loads. Additionally, it was applied in a vertical direction resembling the tissue ward movement as it is the highest percentage of the actual mode of loading occurring in the oral cavity [20].

In the treatment of mandibular implant-supported overdentures, the number of implants used varies greatly according to the condition, it was mentioned that three implants can be placed if the minimum length of each implant is less than 8 mm [21]. It was concluded in another study that staggered arrangement of three implants is preferred in supporting 3-unit partial prosthesis than 2 in-line implants, because the staggered arrangement tend to develop lower bending moments [19,22]. Emami, *et al.* [23] concluded that the treatment of the edentulism by 3-implants overdenture has favorable patient-based outcomes, with negligible perceptions of rotational movement.

There was a significant difference between OT-bar-clip and ball-socket attachments on loading the implants in different sites as the ball-and socket attachment bore somewhat higher axial loads than bar-clip attachment which produces higher implant bending moments. This is because the elements of the bar-clip attachment is more medially placed which produces lateral rocking under unilateral masticatory load, while ball-socket attachments are further apart than the clips which may increase the stability of the prosthesis [24,25].

Ten Burggenkate, *et al.* [26] mentioned that ball and socket attachment does not require an absolute abutment parallelism as it can be rotated up to 28° and does not need large interarch space. Also, Gracis, *et al.* [27] mentioned that ball and socket attachment acts as a resilient attachment and allows multidirectional free movement of the prosthesis, so reduces and more evenly distributes the load transmitted from the implant to the alveolar bone.

Moreover, Meijer, *et al.* [28] mentioned that lower stress values were recorded with the individual implants with solitary anchors may be optimal in atrophic jaws to reduce forces from mandibular flexure. In addition, the solitary ball design is preferable in narrow mandibular arches and with lingually inclined implants to reduce extreme stresses with angular bars. Furthermore, Scherer, *et al.* [29] found that the ball attachment when used with implant-supported overdentures provided the highest levels of retention and stability compared to many other attachments like Locator, O-ring and ERA attachments.

The OT-bar-clip attachment induced higher stresses on the terminal abutment; this could be attributed to the effect of cantilever created by the OT-bar-clip attachment being outside the bar design 7 mm distal to the bar; this extension creates a cantilevering effect. The height of the OT-cap attachment was 0.5 mm from the mucosa, the cantilevering effect with the height of the attachment provided higher bending. Brunski [19], found that for cantilever substructures, no resistance to bending induced a high risk of mechanical overloading for the distal implants. This was evident in all strain gauges and with the three loading positions. These findings were consistent with Kenny & Richards [30], and finite element analysis by Menicucci, *et al.* [24].

The strainmeter has only five channels to read; therefore, a test was done before comparing the two attachment types to choose the best site for strain gauge bonding. This was done by bonding 4 strain gauges on the mesial, distal, buccal and lingual surfaces around one implant, load was applied and a comparison of the resultant strains was done, it was found that the mesial and distal strain gauges had the same reading. Also, the buccal and lingual readings were the same [31]. So, we decided the sites of bonding strain gauges according to this finding.

Load was applied with a magnitude of 99 N which simulates a moderate level of biting force on an implant-supported overdenture [32].

Conclusion

The use of OT-bar-clip attachment for overdentures supported by three implants in hemimandibulectomy cases induces higher stresses on the supporting structure than ball and socket attachment.

Conflict of Interest

The authors declare that there is no conflict of interests regarding the publication of this paper.

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