STRAIN GAUGE ANALYSIS OF AXIAL AND OFF AXIAL LOADING ON IMPLANTS FOR REPLACING FIRST MANDIBULAR MOLAR (INVITRO STUDY)

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ABSTRACT

INTRODUCTION: Mechanical overload is thought to be one of the major causes of implant complications. It may induce loosening and fracture of the superstructure and/or implant components. Bone loss may also occur at the implant-bone interface. Increasing the diameter and length of the implant decreased the stress and strain on the alveolar crest, but diameter had a more significant effect than length to relieve the crestal stress and strain concentration. When the mesiodistal dimension is greater than 14 mm, using at least two implants to restore the region should be considered. When two implants replace the molar region, the mesiodistal offset loads to the prosthesis can be eliminated.
OBJECTIVES: Evaluation of the axial and off axial loading on implants of different diameters for replacing first mandibular molar.
MATERIALS AND METHODS: Fifteen epoxy resin blocks in which implants of different diameters were fixed. Specimens were divided into 3 parallel groups, 5 specimens each according to the implant diameter. Evaluation of the strain distribution around the implants under vertical axial and off axial loading using the strain gauge was done.
RESULTS: The total microstrain mean value of the double implants was significantly less than the 6mm wide implant and the 4.7mm diameter implant.
CONCLUSIONS: On using dental implants for replacing mandibular first molar, double (3.75-3.75) mm diameter implants revealed reducing microstrains than 6-mm-diameter implant and 4.7 diameter implant and give wider support to the crown restoration leading to elimination of the mesiodistal cantilever.
KEYWORDS: Strain gauge analysis, Stress analysis, strain, axial loading.

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INTRODUCTION

The goal of modern dentistry, especially in implantology, is to restore the patient to normal contour, function, comfort, esthetics, speech, and health, whether restoring a single tooth with caries or replacing several teeth (1).

The increased need and use of implant-related treatments in the future result from the combined effect of several factors including consequences of fixed prosthesis failure, poor performance of removable prostheses, predictable long-term results of implant-supported prostheses and advantages of implant-supported restorations (2).

Success of dental implants is commonly defined by implant survival. Implant failure probably results from multi-factorial process. There are various causes related to early (overheating, contamination and trauma during surgery, poor bone quantity and/or quality, lack of primary stability, and incorrect immediate load indication), and late (peri-implantitis, occlusal trauma, and overloading) failure (3).

Ongoing marginal bone loss (MBL) could also put at risk implant survival in the long-term. In 1986, Albrektsson, et al. suggested success criteria for MBL, among other parameters (4).

Recently, the abundance of data regarding MBL, and a better understanding of bone and soft tissue behavior around the implant neck and body, have shown these criteria to be inaccurate for today's wide variety of implant systems (5).

Increased stress (force) on prostheses induces strain (deformation) in the peri-implant bone. Elevated stress and strain could result in the failure of implants that support prostheses (6).

The major types of anchorage unit load are: non-axial and axial loads. The axial force is the most favorable, because it distributes the tension more evenly throughout the implant, while the non-axial load exerts higher gradients of tension on the implant as well as on the peri-implantar bone (7).

Several techniques have been used to evaluate the biomechanical load on implants comprising the use of photoelastic stress analysis, finite element stress analysis, and strain-gauge analysis (8).

Because every molar is not equally wide and long, it is impossible to provide optimal support using only one implant. The double implants give wider support to a molar restoration in both the mesiodistal and the buccolingual dimensions. This should help to preserve and maintain crestal bone and should also provide better support against buccolingual and mesiodistal bending by eliminating the mesiodistal cantilever (9).

This study was an attempt to analyze the axial and off axial loading on implants of different diameter for replacing first mandibular molar using the strain gauge.

MATERIALS AND METHODS

Fabrication of the epoxy resin models

Fifteen polyurethane blocks (40 mm length 14 mm width and 20 mm height) with mechanical properties (young's modulus 3000Mpa) similar to those of mandibular trabecular bone (10) were constructed from silicon mold from a patient diagnostic cast with missing left first molar.

Grouping

The blocks were randomly divided into three main groups (five blocks each) according to the implant diameter used and the fabricated crowns.

Group l: Crown restorations supported on 6 mm dummy implants diameter.

Group II: Crown restorations supported on 4.7 mm dummy implants diameter design**.**

Group III: Crown restorations supported on 3.7 - 3.7 mm double- dummy implants diameter design.

Fabrication of surgical guide stent and implant insertion:

A thermoplastic surgical stent was fabricated for each group to control the position of the implant related to the position of the first molar, and the corresponding implants for each group were inserted according to the placement protocol of used implant system and were tightened with corresponding abutment screws to 35 N-cm with a calibrated torque driver following the manufacturer instructions. Fig. 1(a, b and c)

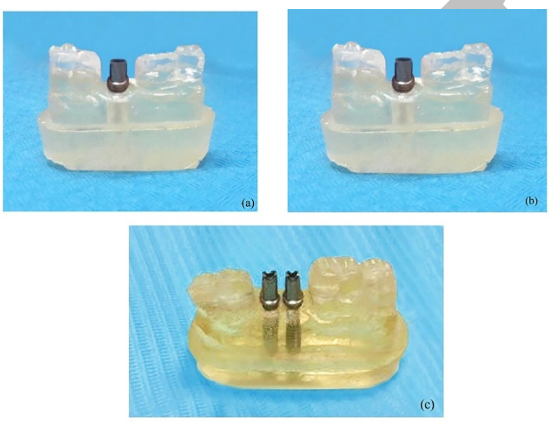

Fig 1: Titanium straight abutments
(a): Titanium straight abutments of 5.7 mm Diameter and 2mm cuff height tightened **on a** dummy implants of 6 mm diameter 13mm length
(b): Titanium straight abutments of 4.5 mm diameter and 2mm cuff height tightened **on a** dummy implants of 4.7 mm diameter 13mm length
(c): Titanium straight abutments of 3.5 mm diameter and 2mm cuff height tightened **on 2** dummy implants of 3.7 mm diameter 13mm length

Construction of crown restorations

Two silicon indexes were fabricated from a full contoured wax-ups of the first molar to standardize the mesio-distal and buccolingual widths of the fabricated wax pattern then sprued, invested and casted, finished and polished according to manufactures instructions.

Each crown was cemented to its corresponding abutment using Medicem, glass ionomer cement according to the manufacturer instructions. Cementation was carried out under static constant load of 1 kilogram for 5 minutes.

Strain measurement

- Four strain gauges (CC-33, EP-34strain gauge) were fixed for each implant facially, lingually, mesially and distally on the epoxy resin model adjacent to the implant site to measure the micro-strains in the medium surrounding the abutment tooth and implant, respectively.
- Strain gauges were bonded to the selected sites using a thin film of methyl-2-cyanoacrylate adhesive (M-Bond 200; Vishay Measurements Group, Raleigh, NC, USA).
- The model was attached to the base of fully digitalized testing machine (LLOYD LR5K instrument) in a horizontal plane.

An Ascending load was applied from 0 to 100 N to different points of the crown using a load applicator attached to the Lloyd testing machine. Fig 2 (a, b, c, d and e)

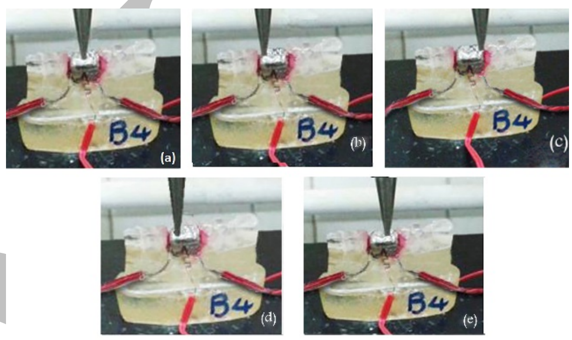

Fig 2: Load application to the crown
(a): Load application to the CF of the crown
(b): Load application to the BL midpoint of the MMR.
(c): Load application to the BL midpoint of the DMR.
(d): Load application to the MBC tip
(e): Load application to the DBC tip.

Loads applied at five different locations:

1- Axial loading at the central fossa of the crown. (CF)
2- Off axial loading at the buccolingual (BL) midpoint of the mesial marginal ridge. (MMR)
3- Off axial loading at the buccolingual midpoint of the distal marginal ridge. (DMR)
4- Off axial loading at the mesiobuccal cusp tip. (MBC tip)
5- Off axial loading at the distobuccal cusp tip. (DBC tip)

The positive and negative strains recorded in the strain gauge analysis were transformed into absolute values, which were used to calculate the mean values of microstrain of each strain gauge.

Statistical analysis of the data

Data were analyzed by Mann Whitney test for abnormally quantitative variables, to compare between two studied groups and Kruskal Wallis test for abnormally quantitative variables, to compare between more than two studied groups. A P-value of less than (0.05) was considered statistically significant.

RESULTS

The total microstrain mean value for the five points of Group I was 151.15με, for the five points of Group II was 381.11 με and for the five points of Group III was 89.05 με.

The minimum micro-strain mean value were recorded in Group **III** (3.5-3.5) mm diameter implant followed by Group **I** (6 mm) diameter implant then Group **II (**4.7mm**)** diameter implant.

- The total micro strain mean values of Group I and Group II were 151.15 με and 381.11μεrespectively and the difference between Group I & II was statistically significant as P value was <0.05.

- The total micro strain mean values of Group II and Group III were 381.11μεand 89.05 με respectively and the difference between Group I and III was statistically significant as P value was <0.05.
- The total micro strain mean values of Group I and Group III were 151.15 με and 89.05 με respectively and the difference between Group I and III was statistically significant as P value was <0.05.
- The total micro strain mean values of Group I, Group II and Group III were 151.15με, 381.11 με and 89.05 με respectively and the difference between the three groups was statistically significant as P value was <0.05.

DISCUSSION

The present study was designed to analyze the strain distribution of the implants replacing mandibular molar under axial and off axial occlusal loads using strain gauge.

Molars replaced by single-standard implants may fracture, while wide implants or multiple implants may withstand the occlusal forces on molars better as suggested by Rangert and Sullivan (11). Therefore, in this study, mandibular molar was replaced by two implants (3.5-3.5mm diameter) compared to a 4.7mm implant and 6mm implant.

The concept of reducing implant-bone stress by means of two implants is a biomechanically more advantageous solution, because it minimizes the mechanical problems such as screw loosening and lowers the stresses on implant and bone (12).

As the total microstrain mean values of the three studied groups were greatly affected by changing the loading sites on the occlusal surface of the crowns, occlusal contacts should be placed as close to the central axis of the implant as possible.

This was in agreement with Frederick DR, Caputo AA. who found that horizontal forces directed to implants may lead to bone resorption or angular defects (13), thus absolute axial loading on implants is required to avoid bending overload (14,15). This can be achieved by using occlusal contacts that provide axial loading and by selecting proper implant diameter and position (16,17).

As reported by Misch, for every 0.5-mm increase in width, there is an increased surface area between 10% and 15% for a narrow range of diameters, and the percentage change is greater for smaller diameters and lesser for larger diameters (18). This was in agreement with Kong et al who found that increasing width of the implant may decrease stresses by increasing the surface area. (19).

The comparison between the three studied groups revealed that the highest strains both in axial and off-axial loading was in Group II(4.7mm). This might be due to the small surface area of the 4.7mm implants, which applies more force per square millimeter against the encasing bone.

These outcomes were in agreement with the results of Seong WJ et al(20) who placed four strain gauges on four locations on a crown supported by a single 3.75mm implant, a 5mm implant, or two 3.75mm implants and found that for all loading conditions, the single 3.75-mm diameter implant consistently experienced the largest strains compared with wide-diameter and double implant designs.

Regarding the effect of implant diameter, the total microstrain mean value of Group III was89.05 με which was the least compared to Group I and II. This might be due to that the type of loading, axial force or nonaxial, did not have an influence until 2 mm as found by Abreu CW (21) who made a strain gauge analysis of the Straight and offset implant placement under axial and nonaxial loads in implant-supported prostheses.

This was in agreement with the study made by Shrikar Ret al (9) who compared the use of single 5mm wide versus 3.7-3.7 double implants for replacing mandibular molar and suggested that the Von Mises elastic strain was reduced by 61% for double implant compared to 5-mm implant.

On comparing Group I and II, Group I resulted in lower microstrains than Group II both in axial and off-axial loading. This may be due to the increased bone-implant contact area and the lower torque effect in conjunction with off-axial loading.

Belshi et al (22) found that the dimensions of the molar crown are usually greater than the diameter of the standard or narrow-size implants resulting in a large bending moments to the bone. Thus, the wide implant can be used at the molar region to reduce the possibility of overloading (23,24).

But this was in disagreement with NJ et al (25) who studied the implant prosthodontic management of partially edentulous patients missing posterior teeth and found that wide implants tend to fail more frequently and Shrikar R et al (26) who stated that the placement of 6mm wide-diameter implant would result in cantilevers of up to 5mm on each marginal ridge of the crown in long span edentulous spaces of more than 12.5mm.

CONCLUSION

On using dental implants for replacing mandibular first molar, double (3.75-3.75) implants were better in eliminating stresses and strains than 6-mm-diameter implant and 4.7 diameter implant and give wider support to a molar restoration leading to elimination of the mesiodistal cantilever.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

REFERENCES

1. Tatum OH. The Omni implant system. Alabama Implant Congress: Birmingham, AL, 1988.
2. Lang NP, De Bruyn H. The rationale for the introduction of implant dentistry into the dental curriculum. Eur J Dent Educ. 2009;13:19-23.
3. Sakka S, Baroudi K, Nassani MZ. Factors associated with early and late failure of dental implants. J InvestigClin Dent. 2012;3:258-61.
4. Liran Levin. Dealing with dental implant failures J Appl Oral Sci 2008;16:171-5.
5. Schwartz-Arad D, Herzberg R, Levin L. Evaluation of long-term implant success. J Periodontol. 2005;76:1623-8.
6. Greenstein G, Cavallaro J, Tarnow D. Assessing bone's adaptive capacity around dental implants: a literature review.J Am Dent Assoc. 2013;144:362-8.
7. Baqain ZH, Moqbel WY, Sawair FA. Early dental implant failure: risk factors. Br J Oral Maxillofac Surg. 2012;50:239-43.
8. Assunção WG, Barão VA, Tabata LF, Gomes EA, Delben JA, dos Santos PH. Biomechanics studies in dentistry:

bioengineering applied in oral implantology.JCraniofac Surg. 2009;20:1173-7.
9. Desai SR, Karthikeyan I, Gaddale R. 3D finite element analysis of immediate loading of single wide versus double implants for replacing mandibular molar. J Indian SocPeriodontol. 2013;17:777-83.
10. Keaveny TM, Guo XE, Wachtel EF, McMahon TA, Hayes WC. Trabecular bone exhibits fully linear elastic behavior and yields at low strains. J Biomech. 1994;27:1127-36.
11. Rangert B, Sullivan R. Preventing prosthetic overload induced by bending. Nobelpharma News. 1993;7:5.
12. Bahat O, Handelsman M. Use of Wide implants and double implants in the posterior jaw: A clinical report. Int J Oral Maxillofac Implants 1996;11:379-86.
13. Brunski B. Biomaterials and biomechanics in dental implant design. Int J Oral Maxillofac Implants. 1988;3:85–97.
14. Reilly DT, Burstein AH. The elastic and ultimate properties of compact bone tissue. J Biomech. 1975;8:393–405.
15. Belshi TJ, Hernandez RE, Pryszlak MC, Rangert B. A comparative study of one implants vs. two replacing a single molar. Int J Oral Maxillofac Implants. 1996;11:372–8.
16. Isidor F. Histological evaluation of peri-implant bone at implants subjected to occlusal overload or plaque accumulation. Clin Oral Implants Res. 1997;8:1–9.
17. Flanagan D. Fixed partial dentures and crowns supported by very small diameter dental implants in compromised sites. Implant Dent. 2008;17:182–91.
18. Misch CE, Bidez MW. A scientific rationale for dental implant design. In: Misch CE (ed). Contemporary Implant Dentistry. 2nd ed. St Louis, Mo: Mosby; 1999: 329–43.
19. Kong L, Sun Y, Hu K, Li D, Hou R, Yang J, et al. Bivariate evaluation of cylinder implant diameter and length: a three-dimensional finite element analysis. J Prosthodont. 2008;17:286–93.
20. Seong WJ, Korioth TW, Hodges JS.Experimentally induced abutment strains in three types of single-molar implant restorations.J Prosthet Dent. 2000;84:318-26.
21. Abreu CW, Nishioka RS, Balducci I, Consani RL. Straight and offset implant placement under axial and nonaxial loads in implant-supported prostheses: strain gauge analysis.J Prosthodont. 2012;21:535-9.
22. Bathe KJ. Finite Element Procedures. Upper Saddle River, NJ: Prentice-Hall, 1996.
23. Qian L, Todo M, Matsushita Y, Koyano K. Effects of implant diameter, insertion depth, and loading angle on stress/strain fields in implant/jawbone systems: finite element analysis. Int J Oral Maxillofac Implants. 2009;24:877–66.
24. Chou H, Muftu S, Bozkaya D. Combined effects of implant insertion depth and alveolar bone quality on periimplant bone strain induced by a wide-diameter, short implant and a narrowdiameter, long implant. J Prosthet Dent. 2010;104:293–300.
25. Attard NJ, Zarb GA. Implant prosthodontic management of partially edentulous patients missing posterior teeth: The Toronto experience. J Prosthet Dent 2003;89:352-9.
26. Desai SR, Karthikeyan I, Singh R. Evaluation of Micromovements and Stresses around Single Wide-Diameter and Double Implants for Replacing Mandibular Molar: A Three-Dimensional FEA.ISRN Dent. 2012; 2012: 680587.