Evaluation of the Biomechanical Response, for the Comparison of Single vs Double Implants Replacing the Mandibular First Molar via a Three-dimensional Finite Element Analysis

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ABSTRACT

Statement of problem: The replacement of the missing mandibular first molar poses a definite biomechanical challenge to the dentist.

Aims and objectives: The study was conducted to evaluate the biomechanical response of the bone, for the comparison of single vs double implants replacing the mandibular first molar via a three-dimensional finite element analysis (FEA).

Materials and methods: A finite model of a section of mandibular bone with a missing first molar and an ADIN Touareg-5 implant with an all-ceramic crown superstructure to replace a missing molar was used in the study.

Results: For each implant design, the loading process 70 N, on three locations (vertical to the long axis), generated von Mises equivalent stress, and resultant displacements. For single implant design, the von Mises stress was found to be 173.61 MPa at the distobuccal cusp tip, whereas for Design 2: Double-implants (3.5 mm-implants), the maximum stress of 145.12 MPa was found at the distobuccal cusp tip.

Conclusion: For the clinical implications of the current analysis, the use of double-diameter implants may be mechanically advantageous in restoring single molars. As they enhance the mechanical properties of the implant system through the increased surface area, stronger resistance to component fracture, increased abutment stability, and enhanced emergence of a profile. To decrease stress, the clinician may elect to increase the number of implants or use an implant design with greater surface area. The greater surface area that is incorporated by the use of the double implant design simulates the roots of the mandibular molar.

Keywords: FEM, Implants, Mandibular 1st molar, Stress analysis.

INTRODUCTION

The ideal goal of modern dentistry is to restore the patient to normal contour, function, comfort, esthetics, speech, and health. What makes implant dentistry unique is the ability to achieve this ideal goal regardless of the atrophy, disease, or injury of the stomatognathic system.¹ For years, patients were advised to place their desires aside and accept the limitations of a fixed partial denture. However, implant dentistry has remodeled the available treatment option for the replacement of a posterior single missing tooth. Dental implant therapy based on the principle of osseointegration to replace the natural tooth has been widely accepted and well documented.²

Implant-supported restorations for fully and partially edentulous patients have exceedingly good long-term success rates.³,⁴ The suggested method of restoring a single implant-supported molar is to control the occlusion by reducing the force level and centering its action relative to the implant axis.⁴

Natural tooth size significantly increases in the molar region and proportionately the root surface area is almost double as compared to the other teeth in the dentition. Therefore, the clinicians face a unique biomechanical challenge. So to achieve the natural crown root ratio, implant diameter is often increased in the molar region for immediate loading, especially when the bone density is less or the masticatory forces are greater.⁵ Mechanical overload appears to be more of a problem with the implant-supported molar crown. Methods suggested improving biomechanics with an implant-supported single molar crown include the use of a wider-diameter implant and the use of two splinted implants to support a single crown.⁶ A recent in vitro model analysis by Seong et al. investigated implant strains associated with three different single-molar implant designs when subjected to various loading conditions. The investigators reported that the double implant design used in the study resisted loads better than the other two designs under most loading conditions.⁷ The complex geometry of the coupled bone-implant biomechanical system prevents the use of a closed-form approach for stress evaluation. Therefore,
the behavior of endosteal dental implants can be investigated by using numerical techniques. Recently, the finite element method has been widely applied to prosthetic dentistry to predict stress and strain distributions at peri-implant regions, investigating the influences of implant and prosthesis designs, the magnitude and direction of loads, and bone mechanical properties, as well as modeling different clinical scenarios. This study aims to evaluate the biomechanical response of the bone by the comparison of single vs double implants replacing the mandibular first molar via a three-dimensional finite element analysis (FEA).

**Aims and Objectives**

A three-dimensional FEA was conducted to compare the induced displacements and stresses as a result of various loading conditions on a mandibular first molar crown supported by a regular 4.2-mm–diameter implant and two 3.5 mm–diameter implants.

**Materials and Methods**

A finite model of a section of mandibular bone with a missing first molar and an ADIN Touareg-S implant with an all-ceramic crown superstructure to replace a missing molar was used in the study.

**Materials**

- A workstation computer with hardware Pentium four processor with 2 GB RAM.
- A 3D CAD Design software: software CATIA v5 R21.
- A FEA (or engineering simulation) software: ANSYS version 14.0.
- Manufacturer data of ADIN Implants with diameters 3.5 mm, 4.2 mm, and length of 10 mm each.
- An all-ceramic crown superstructure (mandibular first molar) was prepared on the model. The details of the external morphology of the crown being sourced from a standard textbook of Dental anatomy. This also was common for all finite element models.

**Methods**

The models were integrated into a single structure in the same software, such that the specified implant with the screw-retained straight abutment was vertically positioned in the bone block with the all-ceramic superstructure.

The 3-D model-Solid mathematical model of implant placed in bone (Fig. 1) was designed to simulate the three single molar implant designs for the comparison of the induced displacements and stresses as a result of various loading conditions on a mandibular first molar crown. The geometric properties of the two implant designs used for the analysis are elaborated in Table 1. The crown was supported by a Design 1: Regular 4.2-mm diameter implant.

Design 2: Two 3.5 mm diameter implants.

The models which were generated were analyzed for a force magnitude of 70 N, directed in the vertical direction. (This was kept constant throughout the study.)

Conversion to finite element model, applying material properties and meshing:

The 3D models were transferred to the ANSYS version 14.0 software for FEA, and Young’s modulus and Poisson’s ratio values of materials were inputted, the values being adopted from the literature, as given in Table 2.

All materials were assumed to be linearly elastic, homogeneous, and isotropic. A state of optimal osseointegration was assumed, i.e., cortical and cancellous bone was assumed to be perfectly bonded to the implant. Meshed Models in the software were obtained (Figs 2 and 3).

This finite element model was divided into small elements. Each element was considered to be interconnected at several discrete points called nodes. Each model was meshed by elements defined

**Table 1: Geometric properties of the three implant designs used for the analysis**

| Implant model  | Diameter | Length |
|---------------|----------|--------|
| 1st (single)  | 4.2 mm   | 10 mm  |
| 2nd (two implants) | 3.5 mm each | 10 mm |

**Table 2: The material properties**

| Material                      | Young’s modulus (GPa) | Poisson’s ratio |
|-------------------------------|-----------------------|-----------------|
| Titanium: implant, abutment   | 11                    | 0.35            |
| Porcelain                    | 68.9                  | 0.28            |
| Mucosa                       | 10                    | 0.40            |
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The results obtained from the FEA simulation showed the relationship between loads applied on the system, geometrical characteristics of materials, joints, and strain. In materials science and engineering, the von Mises stress is used to predict the yielding of materials under any loading conditions from results of simple uniaxial tensile tests. Although formulated by Maxwell in 1865, it is generally attributed to Richard Edler von Mises (1913). The stresses were shown as different colors representing their magnitudes according to the legend given at the side of every figure.

Tables 4 and 5 contain the numerical findings pertaining to the force direction, force magnitude, the von Mises stress (Figs 5 and 6), and the resultant displacement. The results have been described under the designs of the implant-supported molar crown.

**Design 1: Regular Implant: 4.2-mm Implant**

For each implant design, the loading process 70 N, on three locations (vertical to the long axis), generated von Mises equivalent stress and resultant displacements as follows, in the different bone qualities.

**von Mises Stress**

The maximum stress of 173.61 MPa at the distobuccal cusp tip (location C) and the least value of 160.97 MPa at the distal marginal ridge (location B) was observed (Table 4).

**Resultant Displacement**

The range of micro-movements was found to lie between 0.0175 and 0.04 μ/m other highest displacement of 0.04 μ/m was produced at the distal marginal ridge (location B) (Table 5).
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Design 2: Double-implants (3.5 mm-Implants)
For each implant design, the loading process 70 N, on three locations (vertical to the long axis), generated von Mises equivalent stress and resultant displacements as follows, in the different bone qualities. The micro-movements and the stresses around the implant are:

**von Mises Stress**
The maximum stress of 145.12 MPa at the distobuccal cusp tip and the least value of 127.73 MPa at the central fossa (location A) was observed (Table 4).

**Resultant Displacement**
The range of micro-movements was found to lie between 0.009 and 0.02 μ/m. The highest displacement of 0.02 μ/m was produced at the distobuccal cusp tip (Table 5).

**Discussion**
During mastication, overstress around dental implants may cause bone resorption, which leads to infection in the peri-implant region and failure of oral rehabilitation. The way in which bone is loaded may influence its response. The results of cyclic loading into the bone differ from those of static loading. In the case of repetitive cyclic load application, stress microfractures in bone may occur and may induce osteoclastic activity to remove the damaged bone. So far, it is imperative to understand where the maximum stresses occur during mastication around the implants to avoid these complications.

Stresses in dental structures have been studied by various techniques, such as brittle coating analysis, strain gauges, holography, 2-dimensional (2D) and 3-dimensional (3D) photoelasticity, FEA, digital investigations, and other numerical methods. Finite element analysis is a popular numerical method in stress analysis. This method involves a series of computational procedures to calculate the stress and strain in each element, which performs a model solution. FEM circumvents many of the problems of material analysis by allowing one to calculate physical measurements of stress within a structure.

Cibirka et al., in an *in vitro* simulated study, compared the force transmitted to the human bone by gold, porcelain, and resin occlusal surfaces and found no significant differences in the force absorption quotient of the occlusal surfaces among these three materials. Therefore, porcelain was used as the material for the crown superstructure. This study expressed the result (failure criteria) in maximum equivalent stresses (von Mises stresses). The reason for selecting von Mises criteria, which apparently results in a tensile type of normal stress, lies in the fact that the brittle materials (e.g., tooth, bone) fail primarily because of the tensile type of stress.

The models simulated by the FEM analysis in the present study made a comparison between two different designs of the implant-supported molar crown.

For the design variable, the two designs of the implant-supported crown experienced different values of stress and displacements. For the von Mises stress and resultant displacements, the double implant (design 2) performed better (strained less), deformed less than the regular diameter implant (design 1). This result was agreed well with the research observations of the following authors.

In the finite element study done by Geramy and Morgano, the micromotion was found to be better controlled by a wider diameter implant or by incorporation of two implants for a molar implant-supported crown. The reduction in mesiodistal displacement was...
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especially pronounced with the double implant design and this design should be considered when the mesiodistal space for the artificial tooth is larger than average. These results observed by Geramy and Morgano\(^6\) were comparable to the present study.

Balshi et al.\(^12\) stated that two implants for the restoration of a single molar can double the support capacity in the buccolingual direction. These results were comparable to the present FEA.

A radiographic comparison done by Bedi et al.\(^13\) demonstrated the superiority of the use of two standard-sized implants. Their research answered for the shortcomings associated with the wide diameter implants. These findings were analogous to the observations of the present study where the overall significant decrease for the double implant design indicates better clinical applicability.

Petropoulos et al.\(^14\) in his clinical report identified the use of two implants as the most logical solution for the replacement of the missing mandibular molar, to overcome the masticatory overload in pronounced bruxers or clencher.

In an in vitro study done by Seong et al.,\(^7\) for the single-molar implant designs, an increase in implant number and diameter was found to effectively reduce the experimental implant abutment strains. He concluded that the regular diameter implant (design 1) experienced the largest implant abutment strains for all the tested conditions. The results of this study were comparable to the present FEA.

Bayrak et al.\(^15\) conducted a study to evaluate the effect of implant designs with different lengths and diameters on the stress distribution in abutments, implants, and cortical and trabecular bone of the edentulous mandible via three-dimensional FEA. Eight different finite models (cylindrical 3.5 × 6; cylindrical 3.5 × 10.5; cylindrical 4.5 × 6; cylindrical 4.5 × 10.5; triple cylindrical 3.5 × 6; triple cylindrical 3.5 × 10.5; triple cylindrical 4.5 × 6; and triple cylindrical 4.5 × 10.5) were created.

Within the limitations of this study, the triple cylindrical implants, with a new implant design, showed appropriate results in terms of an abutment, implant, and bone tissue stress.

de Carvalho et al.\(^16\) conducted an in vitro study to test different planning options for replacing the mandibular first molar. Two small-diameter implants in an increased edentulous space show more optimized surface strain behavior than a single wide-diameter implant. However, a single 3.5-mm implant also showed reduced strains in the restoration of the same edentulous space. Hence, no significant results were elicited.

Nevertheless, there are limitations to this study design as because of the natural variations in the constants for the mechanical properties of biologic tissue as well as their non-linear behavior, a FEM analysis cannot predict the behavior of biologic tissues and precisely cannot predict the behavior of the inert materials such as metal and porcelain. The vertical occlusal static loads used in the study do not produce the most challenging load transfer within the prosthesis or the surrounding bone. Greater differences are expected between different configurations when oblique loads are used, according to Becker and Becker.\(^17\)

Ideally, two implants should be used to replace a single molar: however, a molar edentulous space is often bound by natural teeth, which results in insufficient mesiodistal bone width for placement of more than one (3.75 mm wide) implant.

The study done by Sato et al.\(^18,19\) evaluated the biomechanical effects of double and wide implants for single molar replacement and concluded that forces for the double implants fluctuated from point to point. As FEM analysis does not consider the clinical complications, Balshi et al.\(^12\) reported higher marginal loss with double implants compared to single implants replacing a single molar. The biological factors, such as potential difficulty in maintenance of oral hygiene with double implant design, which resembles a molar with an advanced furcation invasion, were not taken into consideration for this analysis. The double implants present a greater surgical, prosthetic, and hygiene risk.

Therefore, within the limitations of this present FEA for the design variable, the higher number of implants provides the advantage of the greater seating surface and the greater outer surface area can reduce the stress levels on the implant components and bone-implant interface. Engineering principles suggest that the double implant arrangement provides better support for the artificial crown, and also this implant arrangement closely resembles the naturally occurring anatomic form of the roots of the mandibular molar.

**Conclusion**

Within the limitations of this in vitro FEM analysis, for the three designs of an implant-supported mandibular molar crown, it was concluded that the regular 4.2 mm diameter implant (design 1) produced the maximum micro-movements for the specified loading conditions in comparison to the double implants (design 2). For the clinical implications of the current analysis, the use of double and wide diameter implants may be mechanically advantageous in restoring single molars. As they enhance the mechanical properties of the implant system through the increased surface area, stronger resistance to component fracture, increased abutment stability, and enhanced emergence of a profile.

This study also demonstrated that:

1. In all the tested designs, the number of implants used for the rehabilitation of a single molar significantly affected the micro-movements experienced by the individual implant abutments.
2. The least value for von Mises stress and micro-movements from the vertical intrusive force was recorded for the double implant design.
3. The largest strains were observed at the distobuccal cusp tip. This value was about two times larger than the measured central fossa loading. These findings suggest the precise control of centric contacts on the occlusal surface.

**References**

1. Tatum OH. The Omni implant system. Proceedings of the Alabama Implant Congress, Birmingham, Ala, May 1988.
2. Adell R, Lekholm U, Rockier B, et al. A 15 year study of osseointegrated implants in the treatment of the edentulous jaw. Int J Oral Maxillofac Surg 1981;10(6):387–416. DOI: 10.1016/s0300-9785(81)80077-4.
3. van Steenberghe D, Lekholm U, Boienden C. The applicability of osseointegrated oral implants in the rehabilitation of partial edentulism: a prospective multicenter study of 558 fixtures. Int J Oral Maxillofac Implants 1990;5(3):272–281.
4. Thomas J, Wolfinger GJ. Two-implant-supported single molar replacement: interdental space requirements and comparison to alternative options. Int J Periodont Rest Dent 1997;17:427–435.
5. Terrence J, Griffin DMD, Wai S. The use of short, wide implants in posterior areas with reduced bone height: a retrospective investigation. J Prosthodont Dent 2004;92(2):139–144. DOI: 10.1016/j.prosdent.2004.05.010.
6. Geramy A, Morgano SM. Finite element analysis of three designs of an implant-supported molar crown. J Prosthodont Dent 2004;92(5):434–440. DOI: 10.1016/j.prosdent.2004.08.011.
7. Seong W-J, Korioth TW, Hodges JS. Experimentally induced abutment strains in three types of single-molar implant restorations. J Prosthodont Dent 2000;84(3):318–326. DOI: 10.1067/mpd.2000.109124.

8. Baggi L, Cappelloni I, Girolamo MD, et al. Influence of implant diameter and length on stress distribution of osseointegrated implants related to crestal bone geometry: a three dimensional finite element analysis. J Prosthodont Dent 2008;100(6):422–431. DOI: 10.1016/S0022-3913(08)60259-0.

9. Assunção WG, Barão VAR, Gomes EA, et al. FEA in Dentistry: A Useful Tool to Investigate the Biomechanical Behavior of Implant Supported Prosthesis, Finite Element Analysis - From Biomedical Applications to Industrial Developments. Europe: Dr David Moratal (Ed.); 2012.

10. Sevimay M, Turhan F, Kilicarslan MA, et al. Three-dimensional finite element analysis of the effect of different bone quality on stress distribution in an implant-supported crown. J Prosthodont Dent 2005;93(3):227–234. DOI: 10.1016/j.prosdent.2004.12.019.

11. Sreekha A, Bhattey K. Infinite to finite: an overview of finite element analysis. Indian J Dent Res 2010;21(3):425–432. DOI: 10.4103/0970-9290.70813.

12. Balshi TJ, Hernandez RE, Claudia M, et al. A Comparative study of one implant versus two replacing a single molar. Int J Oral Maxillofac Implants 1996;11(3):372–378.

13. Bedi RS, Verma P, Goel P, et al. Radiographic comparison of the two standardized implants with single wide diameter implant for replacement of one mandibular molar. Asian J Oral Health All Sci 2011;1:4–8.

14. Petropoulos VC, Wolfinger GJ, Balshi TJ. Complications of mandibular molar replacement with a single implant: a case report. J Can Dent Assoc 2004;70(4):238–242.

15. Bayrak A, Yaramanoğlu P, Kılıçarslan MA, et al. Biomechanical Comparison of a new triple cylindrical implant design and a conventional cylindrical implant design on the mandible by three-dimensional finite element analysis. Int J Oral Maxillofac Implants 2020;35(2):257–264. DOI: 10.11607/jomi.7760.

16. de Carvalho EB, Herbst PE, Faria ACL, et al. Strain transfer behavior of different planning options for mandibular single-molar replacement. J Prosthodont Dent 2018;119(2):250–256. DOI: 10.1016/j.prosdent.2017.03.017.

17. Becker W, Becker BE. Replacement of maxillary and mandibular molars with single endosseous implant restorations: a retrospective study. J Prosthodont Dent 1995;74(1):51–55. DOI: 10.1016/s0022-3913(05)80229-x.

18. Sato Y, Shindo N, Hosokawa R, et al. A biomechanical effect of wide implant placement and offset implant placement of three implants in the posterior partially edentulous region. J Oral Rehabil 2000;27(1):15–21. DOI: 10.1046/j.1365-2842.2000.00475.x.

19. Sato Y, Shindo N, Hosokawa R, et al. Biomechanical effects of double or wide effects of double or wide implants for single molar replacement in the posterior mandibular region. J Oral Rehabil 2000;27(10):842–845. DOI: 10.1046/j.1365-2842.2000.00598.x.