ORIGINAL RESEARCH

Finite Element Analysis of Compressive Stress Pattern in Implant-tooth Supported Fixed Partial Denture: An *In Vitro* Study

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ABSTRACT

Aim: The aim of this study was to evaluate the effect of connector design on magnitude and distribution pattern of compressive stress in supporting bone of implant-natural tooth supported three-unit fixed partial denture in distal extension situation.

Materials and Methods: Three-unit fixed partial denture geometric models with lower second premolar as a mesial abutment, missing lower first molar and implant as distal abutment at a second molar place in distal extension situations of the mandibular arch were evaluated using two-dimensional finite element analysis. Three geometric models were constructed with mesial and distal rigid connectors, mesial nonrigid connector, and distal nonrigid connector, respectively, using the software ANSYS: Version 10.0 (University Intermediate). The models were analyzed to evaluate compressive stress at five critical zones under static axial loading (200N) after meshing and assigning the material properties.

Results: The maximum compressive stress concentration values at mesial and distal crestal zone of the implant were −83.33 MPa and −93.30 MPa, respectively, in the model 1. The maximum compressive stress concentration values at the mesial and distal crestal zone of the implant were −51.946 MPa and −45.39 MPa, respectively, with 0.1 mm vertical movement of the connector in the model 2. The maximum compressive stress concentration values at the mesial and distal crestal zone of the implant were −1.768 Mpa and −3.903 Mpa, respectively, with 0.1 mm vertical movement of the connector in the model 3.

Conclusion: In the supporting bone around the implant abutment, the maximum compressive stress concentrations were seen in the crestal zones of model 1 with the rigid connector. In the supporting bone around the implant abutment, the minimum compressive stress concentrations were seen in the crestal zones of models with nonrigid connector.

Clinical Significance: When the implant is used as a distal abutment in distal extension case, it is recommended to place the nonrigid connector in the mesial side of distal implant abutment in implant-natural tooth supported fixed partial denture.

Keywords: Geometric model, Nonrigid connector, Rigid connector.

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INTRODUCTION

"Any edentulous space is a potential implant site," is a global statement can be made in relation to implants. There are many patients for whom the success of conventional removable and fixed prostheses is compromised due to a lack of adequate support, retention, and stability of the resultant prostheses. Implants offer the restorative dentist additional options to obtain these necessary requirements for a successful prosthesis. The advantage of implants is the ability to achieve this goal to some extent regardless of the atrophy, disease or injury of the stomatognathic system.[1] Removable partial dentures used in restoring the partially edentulous situations do cause adverse effects on the health of remaining dentition and surrounding oral tissues in the long run. Patients wearing such prosthesis for longer duration frequently show evidence of the periodontal failure of abutment teeth, enhanced plaque and calculus retention, repeated incidence of caries, and accelerated bone loss in the edentulous area.[1,2] The use of

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dental implants to provide support for prostheses offer a multitude of advantages as compared with removable soft tissue supported prostheses. A primary reason to consider dental implants to replace missing teeth is the maintenance of alveolar bone.[1] Since past two decades, dental implants have been used extensively to achieve successful prosthdontic rehabilitation of edentulism. The documented high survival rate of endosseous dental implants has led to their acceptance as a realistic treatment alternative in modern dentistry.[1-3] However, in spite of the success, it is becoming increasingly clear that successfully integrated implants are susceptible to failure conditions that may eventually lead to loss of the implant. In distal extension, situation cases with missing molars, fixed partial denture can be given connecting mesial natural tooth and distal implant abutment with pontic in between due to various anatomical, surgical, and economic reasons. In such situation, the problems arise due to differences in force distribution and degree of movements of the implant and natural tooth. A well supported natural tooth has movement in the range of 0.1–0.5 mm. An osseointegrated implant has micron movement. The differential mobility is in the range of 5:1, which indicates that when natural teeth and implants are combined in the fixed partial denture, "the implants support the teeth and not the other way around."[2,3] Many clinicians feel that more rigid the attachment in the prosthesis, greater the mutual support between the natural tooth and implant will be. This would be true if were dealing with only natural teeth or only implants. Due to the relative immobility of an implant, it has been suggested that physiological movement of a natural tooth could cause fixed partial denture joining them act as a cantilever thereby creating a bending momentum through the implant into the bone.[4] Due to intimate contact at the bone-implant interface, load applied to the implant is directly transmitted to the alveolar bone. Therefore, the biologic reaction of the osseous tissue is linked with implant longevity. Possible complications of this situation include implant overloading, loss of osseointegration, disuse atrophy of supporting tissues of teeth, failure of fixed partial denture, and implant components.[2-5] This makes it necessary to break the stress generated in the supporting bone around the implant using a nonrigid connector or by intra mobile element.[6] The design of the connectors has principal influence on the stress distribution.[6] Since *in vivo* evidence does take a considerable time to validate the usefulness of the system, stress analysis through finite element method, being a valid, quicker, and reliable, makes it significant.[7-9] With this background in mind, this two-dimensional finite element analysis (*in vitro* study) was planned to evaluate the effect of three-unit fixed partial denture connector design on magnitude and distribution pattern of compressive stress generated in the supporting bone around the implant and natural tooth abutments in distal extension situation under axial loading.

MATERIALS AND METHODS

The software used was ANSYS: Version 10.0 (University Intermediate). The computer used was Intel Core i3, CPU speed: 2.2 GHz (2.8 GHz max turbo boost) Processor, 300 GB hard disc and 2 GB of RAM and an onboard graphics accelerator card. The monitor was a 17´´ flat monitor a refresh rate of 70 Hz.

Methodology

The procedure for the study was as follows.

1. Construction of the three geometric models of the distal extension situation in the mandibular arch of the left side.
2. Meshing of the models.
3. Assigning the material properties.
4. Loading of the models.
5. Analyzing the models.

It involved modeling of an alveolar portion of the mandible (from first premolar area to second molar area) with missing the first molar, implant at the 2nd molar area, first and second premolars. The model 1 had three unit metal-ceramic fixed partial dentures with mesial and distal rigid connectors. The model 2 had three unit metal-ceramic fixed partial dentures with rigid connector between implant abutment and the pontic and nonrigid connector with the mobility of 0.1 mm between the pontic and premolar abutment (mesial connector). The model 3 had three unit metal-ceramic fixed partial dentures with rigid connector between the premolar abutment and pontic and nonrigid connector with the vertical movement of 0.1 mm between the pontic and implant abutment (distal connector). A partially edentulous mandible was measured in superior-inferior plane. The measurements were given coordinates in the x, y planes. It was decided to model only the alveolar portion of the mandible so as to study the stress in supporting bone and to save on analysis time by removing unnecessary parts so that a finer meshwork would be possible. The coordinates were then fed into the computer. Each point was fed in with its x, y coordinates. Connecting the lines of each surface gave the surface geometry or surface model. The height of the mandible portion was 23 mm. The cortical bone thickness was 1.5 mm.[5] The implant used in the study was made up of beta titanium, two-piece parallel walled root-form an endosseous implant. The implant with metal-ceramic prosthesis was modeled according to the Nobel Biocare standard dimensions. The first and second premolars were measured at different points in the superior-inferior plane with the help of vernier calipers. The measurements were given coordinates in the x, y planes. The periodontal membrane width was 0.2 mm.[5] The axes of natural teeth and implants in models were prepared as compatible with the Curve of Spee. A two-dimensional finite element mesh was created using the Ansys Pre-Processor. Care was taken to concentrate the mesh pattern in the region which was to be studied (i.e., in the supporting bone). The element type used was plane 42 with degrees of freedom, translations in x and y directions. All the structures depicted in the model (cancellous bone, compact bone, the teeth, and the implant) were assumed to be linearly elastic, homogeneous, and isotropic. Although cortical bone contains anisotropic material characteristic and regional stiffness variation, sufficient data are unavailable to establish the principle axis of anisotropy, and so it is assumed to be isotropic. The Young's modulus and Poisson's ratio for the different materials used in this study were given by TuncerBurak Ozcelik and Ahmet Ersan Ersoy.[5]

The biting force in the vertical direction was assumed to be 200N. All the three models were loaded with a static axial load of 200N.

Analyzing the Models

The models were analyzed to determine the maximum compressive stress generated in the supporting bone around the premolar and implant abutments for each model at 5 critical zones (maximum value) under static vertical loading.

RESULTS

The stress analysis executed by the Ansys software provided the results that enabled visualization of the stress fields in the form of color-coded bands. Each color band represented a particular value which was given in MegaPascals (MPa). The stress values for the different colors were given at the bottom of each picture. Maximum stress was indicated by the blue zone, and minimal stress was indicated by the red zone. This was followed in ascending order by orange, yellow, light green, dark green, light blue, and dark blue. The three models were evaluated for distribution pattern and maximum compressive stress generated under axial loading in the supporting bone around the implant and second premolar abutments in the models.

Analysis of the Model 1

In the supporting bone around the implant abutment, the maximum compressive stress concentrations were seen in the crestal zones (Figure 1). In the supporting bone around the implant abutment, the compressive stress concentrations were moderate toward the apical third zone. In the supporting bone around the second premolar abutment, the maximum compressive stress concentrations were seen in the cervical zone and distal alveolar crest zone (Figure 1). In the supporting bone around the implant abutment, the maximum compressive stress concentration of −83.33 MPa was seen in the cervical zone. In the supporting bone around the second premolar abutment, maximum compressive stress concentration of −56.509 MPa was seen in the cervical zone (Figure 1).

Analysis of the Model 2

The stress concentrations were reduced in the supporting bone around the implant and the natural tooth abutments (Figure 2). In the supporting bone around the implant abutment, the maximum compressive stress concentration of −51.946 MPa was seen in the crestal zones (Figure 2). In the supporting bone around the implant abutment, the compressive stress concentrations were minimal toward the apical third zone. In the supporting bone around the second premolar abutment compressive stress concentration of −18.269 MPa was seen (Figure 2).

Analysis of the Model 3

The stress concentrations were very minimal in the supporting bone around the implant (Figure 3). In the supporting bone around the implant abutment, the maximum compressive stress concentration of −1.768 Mpa was seen in the crestal zones (Figure 3). In the supporting bone around the implant abutment, the compressive stress concentrations were negligible toward the apical third zone. In the supporting bone around the second premolar abutment compressive stress concentration of −45.463 MPa was seen (Figure 3).

DISCUSSION

The finite element module is a numerical tool which has tremendous power to analyze very complex and irregular bodies.[10] Although it is not a substitute for clinical experimentation, the use of this method of analysis is justified as it stimulates experimental results, reduces experimentation costs and avoids destructive experimentation.[10-12] From an engineering point of view, tooth-implant supported three-unit fixed partial denture may be considered as a multi-component structure consisting of a complex geometry.[13] Whenever such a complex geometry is acted on by a system of forces, it produces a variety of reactions. In an implant supported situation, these reactions can be either stimulatory loading or pathologic overload depending on the magnitude of loads acting on the implant. This should be considered during the planning of implant-natural tooth supported fixed partial dentures.[14,15] The design of connectors in such fixed partial dentures is one of the factors which influence the magnitude and the distribution pattern of compressive stress in supporting bone.[9,16,17] In view of this, it is necessary to biomechanically assess and validate the fixed partial denture connector design which will be most beneficial to its performance with respect to the bone under the loading conditions.[18-20] Finite element analysis is preferable, as it accurately simulates the real-life situation which can be studied in short time duration.[4,5,21] Therefore, this *in vitro* method was selected for the present study, where stress analysis has been carried out to evaluate the effect of connector design in implant-tooth supported fixed partial denture, on magnitude and distribution pattern of compressive stress generated in the supporting bone around the implant and natural tooth abutments in distal extension situation, under static load. A computer simulation operates with several simplifications related to material properties, geometry, load, and interface conditions. For this reason, when applying the results to clinical practice, a qualitative comparison between models is desirable, rather than focusing on quantitative data from the finite element analysis.[5,21] The ramus and the condyles of the mandible were not modeled to save the computer memory, processing time and so that the node density could be concentrated on the required area of the mandible. The advantages of combining natural tooth and implant abutment are the elimination of placement of additional implants, minimum surgical trauma, overriding the anatomical barriers and providing cost-effective prosthodontic treatment.[22]

It was seen that the maximum compressive stress concentrations were in the crestal zones and cervical zones of the supporting bone around the implant abutment in all the models (Figures 1-3). The implant movements in alveolus are at the micron level due to the rigid contact between bone and implant,while masticatory forces compress the natural tooth into alveolus, which causes strain within the implant and supporting bone.[5,9,23] Compared with natural teeth, implant's rotation center is much cervical at the crestal bone level. Therefore, stress accumulation occurred in the crestal bone area, due to the movement of the implant around this rotation center. As we go apically, the compressive stress concentrations were reduced, and very minimal to negligible stress concentrations were found in the apex of the implant.[23]

Comparatively greater compressive stress concentrations were generated in the model with the rigid connectors (Figure 1) than the models with nonrigid connector (Figures 2 and 3). It was noticed that providing optimum vertical movement in the connector allowed stress dissipation to occur, relieving the supporting bone around the implant from the undue compressive stress, and allowed wider stress distribution.

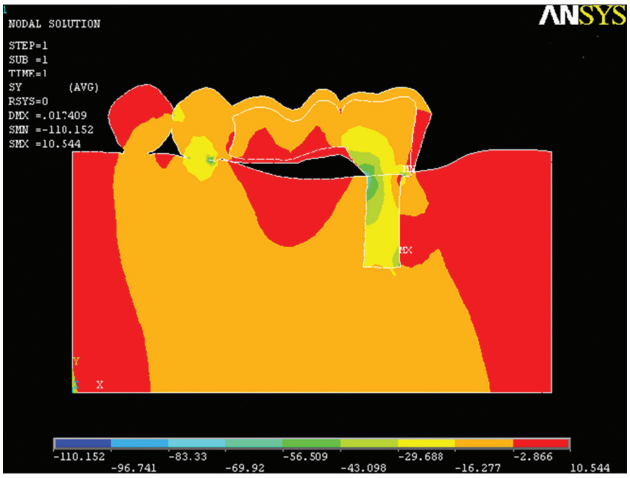


Figure 1: Compressive stress concentrations in model 1

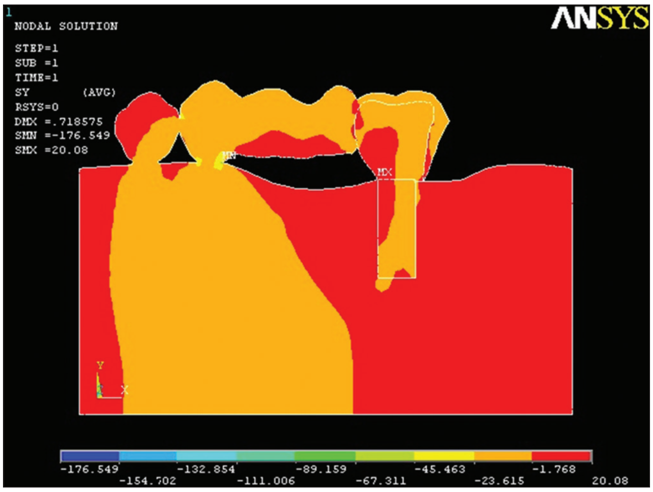


Figure 2: Compressive stress concentrations in model 2

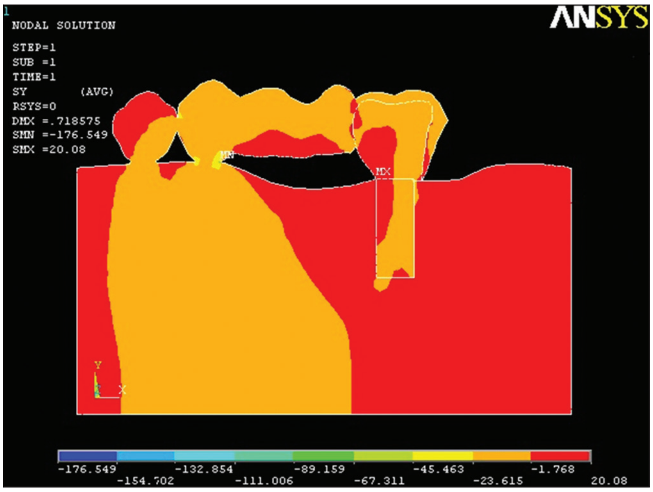
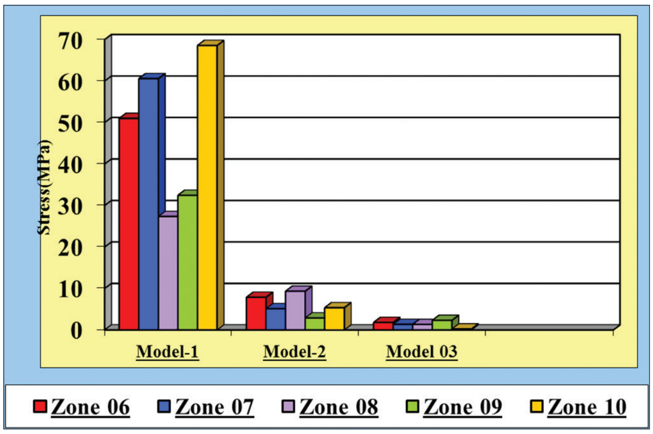


Figure 3: Compressive stress concentrations in model 3



Graph 1: Graphical representation of compressive stress concentrations around the implant in 3 models

These recommendations are consistent with the study, in which a decline in the compressive stress concentrations was seen in the supporting bone around the implant abutment in model 2 and model 3 with nonrigid connectors (Graph 1).

Limitations of This Study

The simulation of the supporting tissues as homogenous, isotropic, and linearly elastic structures is an obvious simplification.

Assumption of the complete continuous direct contact of the bone to the implants which may not be feasible clinically.

Hence, long-term *in vivo* study to support the above tests may be carried out.

CONCLUSION

In the supporting bone around the implant abutment, the maximum compressive stress concentrations were seen in the crestal zones of Model 1 with the rigid connector.

The compressive stress concentrations were reduced in the supporting bone around the implant and the natural tooth abutments models with nonrigid connector.

In the supporting bone around the implant abutment, the minimum compressive stress concentrations were seen in the crestal zones of models with nonrigid connector.

The compressive stress concentrations were very minimal in the supporting bone around the implant in model 3 with the distal nonrigid connector.

In the supporting bone around the implant abutment, the compressive stress concentrations were minimal toward the apical third zone in all the models.

The compressive stress concentrations were minimal in the cervical zone of supporting bone around the implant and the natural tooth abutments in the models with the nonrigid connector.

Clinical Significance

It may be recommended that when mesial natural tooth and distal implant are used together as abutments for three-unit fixed partial denture prosthesis in distal extension situation, the nonrigid connector may be placed on the mesial side of the distal implant abutment.

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