A Three-Dimensional Finite Element Analysis to Evaluate Stress Distribution Tooth in Tooth Implant-Supported Prosthesis with Variations in Non-rigid Connector Design and Location

Abstract

Background: The physiologically mobile natural tooth and rigidly fixed dental implant causes different distribution of stress when connected in prosthesis and nonrigid connector compensates this. Understanding of biomechanical behavior is necessary for an adequate choice and construction of this type of rehabilitation. However, there has been insufficient research focusing on different location and type of the nonrigid connector related with the prognosis of both implant and the tooth. Aim of the Study: The purpose of this finite element (FE) analysis was to evaluate the stress distribution around bone, implant, and tooth in tooth implant fixed prosthesis under static load with variations in design and location of nonrigid connectors under simulated functional loads. Materials and Method: Three, 3-dimensional FE models connecting tooth and implant were constructed with different location and type of nonrigid connector. Simulated occlusal load was applied on the restorations and stresses developed in the supporting structures were monitored. Results: The highest stresses were found around the implant in model with nonrigid connector placed between the tooth and implant and model with modified nonrigid connector. On the other hand, less stress was noted around the implant where nonrigid connector was placed between the implant and pontic. Conclusion: It is advisable to place the nonrigid connector between the implant and the pontic to protect the implant from torque effects in a tooth implant fixed prosthesis.

Keywords: Finite element analysis, nonrigid connector, tooth implant-supported prosthesis

Introduction

Implant dentistry is a revolutionary improvement in functional and esthetic rehabilitation of both partially and completely edentulous conditions. Although many treatment options such as cast partial denture and freestanding implant-supported restoration are available for distal extension situations, tooth implant fixed prosthesis has shown efficient treatment alternative for patients with anatomic and economic limitations.[1-2] Teeth with a sound periodontal ligament have mobility characteristics between 50 and 200 µm, while osseointegrated implants demonstrate a mobility of <10 µm.[3-7] This difference in mobility has been associated with a number of problems such as intrusion of abutment teeth,[1,8,9] abutment screw loosening,[7,8] fracture of abutment teeth, and fracture of implant components.[7,10] This can be compensated by nonrigid connectors, which act as stress breaker with the ability to separate the splinted units. Cohen and Orenstein claims that the nonrigid connection between teeth and implant limits cantilever forces and directs occlusal loads axially to the implant.[11]

The different nonrigid connectors systems available are (1) implant with a stress-absorbing element (intramobile element or stress-breaking element)[12] and (2) Key and Keyway stress breakers which are commonly used with conventional FPDs.[13-15] Chee and Jivraj designed a nonrigid connection between implant and pontic with spoon-shaped rest from distal attachment to the pontic seated on tooth implant-supported restoration.[16,17]

Theoretically, the suggested nonrigid connections between implant-supported crown and the pontic will transfer favorable occlusal load. However, there has been insufficient research focusing on the connector designs used on tooth implant fixed prosthesis. One of the important reasons is that many clinical observations

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could not have sufficient enough information to determine the biomechanics of complicated tooth implant supported systems. Computer simulations based on the finite element (FE) method has been employed as a tool for evaluating mechanical responses such as internal stresses or relative micromotions. Hence, three-dimensional (3D) FE analysis was used to assess the stress distribution around bone, natural tooth, and implant under occlusal load on tooth implant fixed prosthesis with different nonrigid connector design and location.

**Materials and Methods**

A 3D FE analysis was conducted using mathematical models of posterior 3 unit tooth implant-supported prosthesis with a nonrigid connector. The different design and location of nonrigid connector were divided into 3 models as:

- Model 1 - Nonrigid connector placed on mesial side of implant [Figure 1]
- Model 2 - Nonrigid connector placed on distal side of premolar [Figure 2]
- Model 3 - A passive connection in the form of a removable partial denture type spoon-shaped rest extending from the distal surface of the pontic and rest seat preparation on the restored implant. On the mesial side of the pontic, it was rigidly connected to the tooth [Figure 3].

A computed tomography image of adult mandible was used to make the 3D model of second premolar tooth with edentulous mandible distal to it. Modeling was done by using a Pro/Engineer Software (Parametric Corporation, Technology Needham, MA, USA) and exported to an analysis package. A bone block with height of 29 mm, width of 12 mm, and cortical bone thickness of 1.5 mm surrounding the cancellous bone was modeled. The model of premolar tooth was simulated with root length of 13 mm, crown length of 8 mm, mesiodistal and buccolingual diameter of 8 mm in accordance to Wheelers Atlas of Tooth form. The periodontal ligament of 0.2 mm width was simulated. General rule of tooth preparation was followed for metal-ceramic restoration with chamfer margin. Physical models of implant of length 13.5 mm and width 3.45 mm were converted to their geometric model and simulated to be placed in section of mandibular bone at the second molar region. The implants were directly in contact with the bone while natural tooth had mobility within the borders of the periodontal membrane.

A metal-ceramic restoration was simulated with Ni-Cr alloy substructure and finished with feldspathic porcelain for tooth implant-supported prosthesis. Two types of nonrigid connectors were used in the study - Beyeler intracoronal, friction grip, dovetail slide key and keyway attachment (Cendres and Metaux, Switzerland) with the fixed length 3.8 mm. Other model of nonrigid connector was made with an occlusal rest extending from the distal surface of the pontic and a spoon-shaped rest preparation on the restored implant. The dimensions of rest seat were taken from the literature. Both the non rigid connectors were allowed to move vertically on each other where their surfaces were in contact.
The cortical bone, the trabecular bone, implant and its abutment, and mucosa were modeled. The elastic modulus and Poisson’s ratio of titanium, trabecular, cortical bones, periodontal ligament and dentin, and feldspathic porcelain were obtained from the literature[^22] and listed in Table 1. All the materials used in the models were considered to be isotropic, homogeneous, and linearly elastic, and the osseointegration of the implants was accepted as 100%. The finite element software, ANSYS Workbench Software (Santa Monica, CA, USA) was used to analyze the models.

### Boundary

Considering the support of masseter and medial pterygoid muscles that attach to the external angle of mandible, the boundary condition with no displacement was prescribed for the nodes near the angle of the mandible at the level of occlusal plane, improving the model mimicry and accuracy.[^23]

### Loading condition

This study was designed with the tripod occlusal contacts of the supporting cusps of premolar and both the molars loaded at buccal cusp tip, mesial, and distal fossa.[^24] A load of 300 N[^25] was applied as 37.5 N at each location in the vertical direction. The maximum equivalent von Mises stress values at the implant, cortical and trabecular bone and abutment tooth were recorded [Figure 4].

### Results

The results obtained were tabulated [Table 2] and also shown in Figures 5-7.

#### Stress at cortical bone

The maximum stress distribution in the cortical bone near the tooth was found in Model 2 (50.63 MPa) among the 3 models and less in Model 1 (35 MPa) and stress of cortical bone near the implant, the value was high in Model 3 (30.9 MPa) and again less in Model 1 as represented in Graph 1.

#### Stress at trabecular bone

The value was significantly high in Model 1 in both trabecular bone near tooth and implant (6.15 MPa and 17.85 MPa) as compared to the other models and shown in Graph 2.

#### Stress at implant

Less stress distribution was found in Model 1 (40.59 MPa) as compared to the other two. Maximum stress was transmitted in both Model 2 and 3 and the values were almost were same (44.22 MPa and 44.33 MPa, respectively) as shown in Graph 3.

#### Stress at abutment tooth

The maximum stress value was lower around the abutment tooth in Model 2 (37 MPa) and it was highest in Model 1 (59 MPa) as given in Graph 4.

### Table 1: Modulus of elasticity and Poisson’s ratio of various materials used in the study

| Material               | Modulus of elasticity (G Pa) | Poisson’s ratio |
|------------------------|------------------------------|-----------------|
| Implant                | 110                          | 0.33            |
| Cortical bone          | 15                           | 0.30            |
| Trabecular bone        | 1.5                          | 0.33            |
| Pulp                   | 0.002                        | 0.45            |
| Periodontal ligament   | 2                            | 0.45            |
| Ni-Cr alloy            | 218                          | 0.33            |
| Porcelain              | 60                           | 0.45            |
| Nonrigid attachment    | 110                          | 0.33            |

[^22]: Literature reference
[^23]: Additional research reference
[^24]: Additional research reference
[^25]: Additional research reference
In Model 1 (with NRC placed on the mesial side of the implant), the values were 59.09 and 35.4 around the tooth and in the cortical bone region around the tooth, respectively. The highest stress value in the cortical bone around the implant was 20.43 and 40.59 on the mesiocervical region of the implant.

In Model 2 (with NRC placed on the distal side of the premolar tooth), the highest Von Mises stress values located in the cortical bone region around the tooth was 50.63 and 37 around the tooth. The highest stresses in the cortical bone region around the implant were 28.05 and 37 on the mesiocervical region of the implant.

In Model 3 (with NRC as occlusal rest on the distal surface of the pontic positioned on the rest seat prepared on the mesial side of the implant restoration), the highest stress values obtained were located on the cortical bone region around the tooth than around the tooth with the values 43.93 and 41.2, respectively. The highest stress values were generated around the implant than in the cortical bone with the values 44.3 and 30.94, respectively. In all the 3 models, the stress around the natural tooth and implant abutment was found to be gradually decreasing from the crestal region of the bone to the apical region.

### Table 2: Stress values around the cortical and trabecular bone, implant, and tooth after application of load

| Stress values around  | Model 1  | Model 2  | Model 3  |
|-----------------------|----------|----------|----------|
| Cortical bone near tooth | 35.409   | 50.63    | 43.93    |
| Cortical bone near implant | 20.435   | 28.05    | 30.94    |
| Trabecular bone near tooth | 6.15     | 2.009    | 2.04     |
| Trabecular bone near implant | 17.854   | 3.27     | 2.76     |
| Implant                | 40.59    | 44.2     | 44.33    |
| 2nd premolar           | 59.099   | 37       | 41.2     |

Discussion

In modern implantology, freestanding implants are the most preferred ones. A single implant can also serve as an abutment for several types of restoration including cantilever or tooth implant restoration. The use of cantilevered pontic supported by natural tooth as abutment in posterior areas has to be used cautiously because of the magnitude and axial direction of occlusal forces that are placed on the pontic of restoration. The dissimilar mobility between an osseointegrated implant and tooth causes a dilemma in connecting an implant and tooth. The capability of a tooth to move and biomechanical aspects of tooth implant-supported prosthesis are significantly influenced by the viscoelastic properties of periodontal ligament. It plays a key role in long-term performance of...
tooth implant-connected prosthesis.\textsuperscript{[4,5]} A nonrigid connector is advised for homogeneous load distribution. It also relieves the stress and overload between the structures or long-span prosthesis.\textsuperscript{[31]} Major risks that arise by connecting tooth and implant are bone loss around implant and natural tooth intrusion. The causes for tooth intrusion are multifactorial such as friction between the matrix and patrix wall in nonrigid connector and microjamming of food particles at the bottom of the matrix preventing tooth from reconnecting to its original position.

Chee and Jivraj reported a design to eliminate intrusion of tooth by using a modified nonrigid connector. A nonrigid connection in the form of a deep removable partial denture-type spoon-shaped rest was fabricated on the distal of pontic, and corresponding rest seat was prepared on the implant.\textsuperscript{[16]} In this study, this was used to compensate the dissimilar mobility of tooth implant in tooth implant-supported prosthesis. The stress transmitted to the bone, implant, and tooth were evaluated after application of vertical load. The highest Von Mises stress values were taken into consideration and survival of the implant in all models was compared.

Duyck \textit{et al.} demonstrated a better distribution of bending moments when metal was used as a restoration material in cantilevered or long-span prosthesis.\textsuperscript{[32]} Ni-Cr alloy was used as a substructure in the study. Cibirka \textit{et al.} compared the forces transmitted to human bone by gold, porcelain, and resin occlusal surfaces and found no statistically significant difference in the force absorption quotient of the occlusal surfaces.\textsuperscript{[33]} In the current study, porcelain was used for occlusal surface.

Less Von Mises stress around implant was observed in Model 1 among the 3 models. This was due to the location of nonrigid connector between the implant and the pontic which allowed the implant to receive less stress, and greater part of the occlusal force was borne by the tooth. Ozcelik, Ersoy evaluated the stress around the implant and the abutment tooth with different location of nonrigid connector using 2D-FEM models and Photoelastic stress analysis method. There was a decrease in stress formed on the implant side in both the methods and in which nonrigid connector placed between implant and pontic.\textsuperscript{[22]} A similar outcome was observed by Koosha and Mirhashemi in their study.\textsuperscript{[34]} Beehelli suggested that nonrigid connector in tooth implant-supported prosthesis should be placed on the implant side to protect it from the torque effects.\textsuperscript{[35]} He also indicated the advantages of this design such as allowing physical movement of the natural tooth, equal distribution of forces on the implant, and the natural tooth.

More stress distribution was found around the implant in Model 2. Kumar \textit{et al.} noticed higher amount of stress around the implant than the tooth in a model where nonrigid connector was placed on the tooth side in their study.\textsuperscript{[36]} The reason stated for this may be that additional movement of the pontic under occlusal forces caused the bridge to produce a cantilever effect on the implant. Thus, nonrigid connector placed on the tooth side had more disadvantages than the fixed prosthesis that is rigidly connected. The studies conducted by Misch and Ismail\textsuperscript{[37]} and Breeding \textit{et al.}\textsuperscript{[38]} reported that there was no difference between the tooth implant-supported prosthesis with rigid connector and nonrigid connector placed on mesial side of the pontic.

No significant difference in stress value was found between Model 2 and 3. The nonrigid connection in a form of spoon-shaped occlusal rest could allow only a minimal movement and behave more or less like a rigid connection. A rigid restorative condition resolves more stress internally before it can reach the supporting tissues. This could be the reason for increased stress around implants and less stress around the natural tooth. Furthermore, \textit{in vivo} and \textit{in vitro} studies are needed to evaluate the biomechanical behavior of this kind of nonrigid connection.

More stress was found on the mesiocervical region of the implant in all the models. The reason could be disparity in the mobility of tooth and that of implant which was assumed as 100% osseointegrated. The bending moment which occurs after the applied static vertical load intrudes the natural tooth into the alveolus causes more stresses on the mesiocervical region of implant because the rotation center of implant is much higher than the natural tooth at the crestal bone level. Therefore, stress accumulation occurs in the cortical bone area due to the movement of the implant around this rotation.\textsuperscript{[22,34]} The higher amount of stress was noted around the natural tooth in Model 1 as compared to Model 2 because of the location of the nonrigid connector which allows receiving less stress.

All static masticatory forces applied were loaded vertically in this study. However, the masticatory forces are dynamic and may be directed oblique to the occlusal surface of tooth implant-supported prosthesis. Consequently, it is usually impossible to reproduce all details of natural behavior in a mathematical model which might influence the study outcomes.\textsuperscript{[39]} Due to these limitations, the values obtained in this study may not resemble actual values but can definitely show the stress differences and advantages of various tooth implant-supported designs.

**Conclusions**

The following conclusions may be drawn from the study:

1. The nonrigid connector in tooth implant fixed prosthesis should be placed on the implant side to protect the implant from the torque effects
2. There was no significant difference in the stress values around the implant between the nonrigid connector placed between abutment tooth and pontic and RPD type spoon-shaped rest extending from the distal surface
of the pontic seats into rest preparation on the restored implant.

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Conflicts of interest
There are no conflicts of interest.

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