International Journal of Orthopaedics Sciences

ISSN: 2395-1958
IJOS 2019; 5(2): 923-926

www.orthopaper.com
Received: 14-02-2019
Accepted: 18-03-2019

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Evaluation of stress between rigid and non-rigid connector design in implant supported prosthesis: An *in vitro* study

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DOI: https://doi.org/10.22271/ortho.2019.v5.i2n.112

Abstract
The effects of rigid/non-rigid connectors and stress absorbing elements on mechanical behavior of TISP were studied using 2D finite element analysis. Finite element models were created in DISPLAY III software and were subjected to a static occlusal load of 75N. The use of non-rigid connector increased the stress (17.7 N/mm^2) on the implant neck when compared to rigid connector (10.25 N/mm^2) and stress absorbing element (8.49N/mm^2). Maximum displacement of the TISP (18.74 µm) was seen with a non-rigid connector.

Keywords: Connector design, finite element analysis, stress absorbing element

Introduction
Management of distal extension edentulous space is always challenging, because of the fact that, the distal extension partial dentures derive their support from tooth as well as the underlying mucosa, and residual alveolar ridges. This extension base type of denture will always be subjected to rotational movement in relation to the three cranial planes due to the difference in the support characteristics of the abutment teeth and the soft tissue covering the residual ridge. As a result it is difficult to achieve maximum stability and masticatory efficiency without counteracting the rotational torque forces due to lack of abutment support on the distal side.

This problem can be overcome by creating an abutment support on the distal side by using an implants a distal abutment to [4, 5]. By placing an implant on the distal aspect of the Kennedys class II edentulous arch, we gain a lot of mechanical advantage, because of elimination of the rotational torque forces which would otherwise act on the free end of the denture base of a distal extension partial denture. Now the prosthesis is actually FPD i.e. a Tooth Implant Supported Prosthesis with one abutment being a natural tooth and the other abutment being an implant. But because of the difference in attachment of the natural teeth vs implant to the bone, they respond differently when an occlusal load is applied to them.

The natural tooth is anchored to the socket by periodontal ligament, which permits little movement every time an occlusal load is applied. Because of this support, the tooth bounces back to its original position on removal of the occlusal forces.

On the other hand, implants Osseo integrate directly into the bone without a periodontal ligament. So it does not have the advantage of cushioning effect provided by the periodontal ligament whenever subjected to an occlusal force. This results in intrusion of the implant in due course of time, resulting in its failure.

Apart from this there are also many other reasons advocated for intrusion of implants like flexion of the FPD framework, impaired rebound memory in the implant abutment due to its rigid anchorage to the bone, etc.

Because of intrusion, there develops stress and bone resorption around the neck of the implant which might in turn lead to marginal bone loss, fracture of the implant, ultimately resulting in failure of the implant. Our study aims at analyzing if there is any intrusion of implant abutment in a TISP, the amount of intrusion, and whether it is affected by factors like connector design of the FPD and presence of stress absorbing materials.

Material and Methods

The objective was mainly to study the stresses due to vertical occlusal loads and to observe the effect of various connector designs, effect of stress absorbing element (SAE) on stresses transferred to a 3-unit tooth-implant supported prosthesis (TISP) and to study the displacement of the tooth and the implant in each situation. Finite element analysis is a non-invasive and reliable tool in analyzing the biomechanical properties of implants. This is basically a numerical method of studying the stresses, deformations and displacements of tooth and implant within a given geometry. A 2D finite element method is preferred for its simplicity. The structure is discretized into the so-called finite elements connected through nodes. A finite element model is then made. The loading and boundary conditions are specified to simulate the necessary conditions.

Creation of finite element model

Unilateral Kennedy's Class II distal extension edentulous arch with missing mandibular first, second and third molar was chosen. The remaining teeth in the arch had good periodontal health and optimum bone support. The missing first and the second molars were restored using a TISP with the second premolar and an implant in the second molar region as abutments. A root form of screw implant (Pitt-Easy Bio-Oss) having a height of 10mm and width of 4.9mm was used. A radiograph of the prosthesis was made and was scanned to generate an image in JPEG format. Then the image was converted into IGES format which was used in model construction in DISPLAY III software (Solver Engineering, Voronezh, Russia). The root form screw implant was designed as one piece implant serving as the distal abutment. The models generated are shown in figure 1. The dimensions of the teeth, supporting structures and the implant are summarized in Table 1.

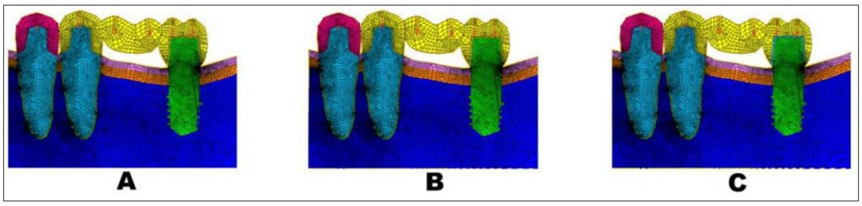


Fig 1: A) Model 1-rigid connector B) Model 2 - non-rigid connector C) Model 3 –SAE

Table 1: Dimensions of FEA model

Dimensions of the teeth and supporting structures	Dimensions of the implant
Crown length=8mm Root length = 14.5 mm Width of the periodontal ligament = 0.25 mm Length of mucosa = 2mm Length of trabecular bone = 15mm Length of cortical bone = 1.5 mm	**Body:** Length: 10mm,Diameter: 4.9mm **Neck:** Length: 2mm, Diameter: 2mm **Head:** Length: 4mm, Diameter: 4mm

Three unit fixed partial denture models were created with variations in the connector type, with the presence of a stress absorbing element. The list of various models along with the number of nodes and elements are given in Table 2.

Table 2: The list of various models along with the number of nodes and elements

Model	Connector Design	Absorbing Element (SAE)	Elements	Nodes
Model 1	Rigid	-	20055	20303
Model 2	Non-rigid	-		
Model 3	Rigid	Present		
Model 4	Rigid	-	23781	24030
Model 5	Rigid	-		
Model 6	Rigid	-		
Model 7	Rigid	-		
Model 8	Rigid	-		
Model 9	Rigid	-		

Boundary conditions and application of load

There are three boundaries namely the anterior boundary, posterior boundary and the base. The anterior boundary was modeled as an elastically deformable support with stiffness of $2N/mm^2$. The posterior boundary and base supports were considered fixed. The contact between the second and the first premolar was modeled using gap applications to get the effect of non-linear analysis. A biting force of 75 N was used in this analysis.

Analysis and post processing

The model created in DISPLAYIII was analyzed in software NASA II (Solver Engineering, Voronezh, Russia). A linear-static analysis was performed. Output of the analysis was done in the post-processing module of DISPLAY III software. The stress on the implant and the tooth were calculated using Von Mises stress values. Von Mises stress represents the overall stress at any given point and is most commonly used in FEA studies.

Results

Stress distribution in TISP

TISP with rigid and non-rigid connections

Figures 2A and 2B show the stress distribution in TISP with rigid and non-rigid connections. In model 1 and model 2 the stresses were concentrated on the mesial side of the neck of the implant. In the presence of a non-rigid connector the stresses were more concentrated on the implant than on the abutment tooth. The Von Mises stresses in models 1 and 2 at the neck of the implant were 10.25 N/mm^2 and 17.25 N/mm^2 respectively.

TISP with a SAE

Figure 2C shows the stress distribution in TISP with a SAE. When compared to model 1, the stresses in model 3 were more evenly distributed among the tooth and the implant. In model 3 the maximum stresses were observed on the mesial side of the neck of the implant and on the connector between the abutment tooth and the pontic. The Von Mises stress at the neck of the implant was 8.49 N/mm^2.

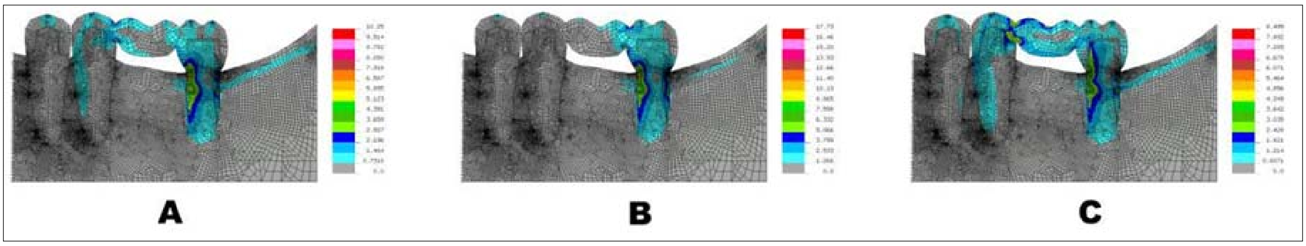
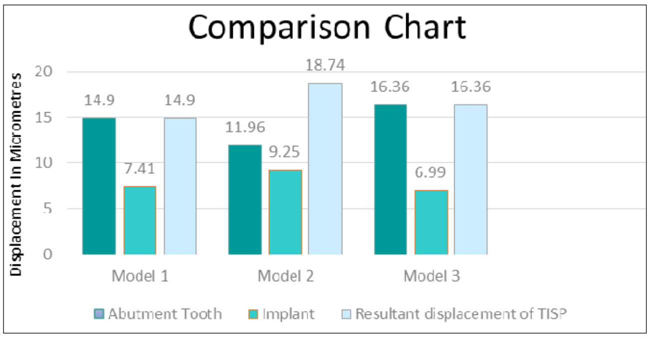


Fig 2: Stresses observed in TISP with A) Model 1 - rigid connector, B) Model 2 - non-rigid connector, C) Model 3 – SAE

Displacement in TISP

TISP with rigid, non-rigid connections and SAE

The graph 1 shows the displacement of tooth, implant and the resultant displacement of the TISP in models 1-3 respectively. The resultant displacement of model 1 (14.90 µm) was lesser than that observed with model 2 (18.74 µm) and model 3 (16.36 µm). This showed that the use of non-rigid connector or SAE increased the displacement of the TISP compared to rigid connections.



Graph 1: Comparison of displacements of abutment tooth, implant and resultant displacement of TIPS in models 1, 2 and 3

Discussion

The present study used a 2D finite element method to analyze the stress distribution and displacement of a 3-unit TISP. Our study compared the parameters viz., effect of connector design, stress absorbing element, and displacement of TISP using similar finite element models with same material properties and under same occlusal load. This allowed us to make meaningful comparisons among the various parameters within the models and also to study whether these observations were similar to those reported in previous studies.

In our study, it was found that the maximum stress concentration was at the neck of the distal implant. This is similar to the results observed in other finite element studies.

In model 2, the non-rigid connector was placed between the abutment tooth and the pontic. The abutment tooth in model 1 was displaced more (14.90 µm) than in model 2 (11.96 µm) and the implant was displaced less in model 1 (7.41 µm) than in model 2 (9.25 µm). Thus in the presence of a rigid connector the TISP tends to be cantilevered around the distal implant resulting in resulting in greater displacement of the abutment tooth. This phenomenon could be the reason for intrusion of the abutment teeth in TISP as described by some authors. This concept is contradicted by other reports in which no tooth intrusion occurred with a rigid connector.

The use of non-rigid connector caused the opposite effect and thus is expected to cause less intrusion of the tooth. But clinically the use of non-rigid connection was found to be more dangerous than using a rigid connection resulting in greater tooth intrusion. Some investigators have even abandoned the use of non-rigid connectors. The intrusion of abutment tooth in these situations can be explained by two mechanisms which prevent the tooth from returning to its original position after an occlusal load. The first may be due to entrapment of food debris or calculus between the tooth and the framework (debris impaction or micro-jamming). The second may be due to frictional resistance provided by the male and the female parts of the non-rigid connector (ratchet effect). It may be concluded that the use of a rigid connector is better than a non-rigid connector as the resultant displacement in TISP was less with a rigid connector.

Conclusion

This study is not without limitations. All the materials used were considered to be homogeneous, isotropic and linearly elastic. But in reality the properties of the materials may vary. The study used a one piece implant as the distal abutment. A two piece implant may give different results from those obtained. The thickness of the cement layer was ignored in this study. Careful choice of prosthetic options by the clinician is of paramount importance in achieving clinical success.

Inspite of complications like intrusion, implant supported fixed partial dentures are still an efficient modality in treating complicated edentulous spaces like distal extension [Kennedy's class II], because of the stability they provide. Also they can be used in these conditions to avoid unnecessary cantilever type of FPD Further studies are needed to explore the possibility of successfully using implants in Tooth and Implant Supported Prostheses.

Within the limitations of the study it can be concluded that:

1. Use of non-rigid connectors increased the stresses and displacement in a TISP
2. A rigid connector is preferred over a non-rigid connector in a TISP

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