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"Comparative Evaluation of Stress Distribution in Tooth - Implant Supported Prosthesis with Different Implant Location Using Non-Rigid Connector – A Finite Element Analytical Study"

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ABSTRACT:

Aim and objective: To evaluate the stress distribution in tooth - implant supported fixed partial denture with different implant location and non-rigid connector on the mesial side of the pontic using finite element analysis method.

Materials and Methods: The cone beam computed tomography (CBCT) images of the mandible will be converted to stereolithography file. HYPERMESH-11 software will be used to convert 3D images into numerical models. Geometric model of the implant, Ni-Cr, non-rigid connector will be created using SOLID EDGE V19 software. The material properties (young's modulus and poisson's ratio) to represent physical properties of cortical bone, cancellous bone, implant and non-rigid connector will be taken from the standard textbook of dental materials and implantology. A total of two models will be constructed**, MODEL-1** Second right molar (implant) and first right molar (pontic) are connected by a rigid connector, first right molar (pontic) and second right pre-molar (natural tooth) are connected by a non-rigid connector. **MODEL-2** Second right pre-molar (implant) and first right molar (pontic) are connected by a non-rigid connector, first right molar (pontic) and second right molar (natural tooth) are connected by a rigid connector. Each fixed partial denture was subjected to a static load of 50N on the second pre-molar and 100N on the first molar and second molar vertically parallel to the long axis of the tooth.

Results: The overall maximum principal stress are 321.321mpa & 314.959mpa in MODEL 1 and model 2 respectively. The overall von mises stress are 256.071mpa & 239.818mpa in MODEL 1 and model 2 respectively.

Conclusion: The results of the study concluded that regardless of the implant and the teeth location the stresses are higher within the framework and supporting structures of the fixed partial denture when connected by a rigid connector. The non-rigid connector demonstrated better load distribution, within an absence of tension in the trabecular bone in both prostheses.

Key words: Finite element analysis (FEA), Biomechanics, Implants, Tooth-implant supported fixed partial dentures.

I. INTRODUCTION

The use of osseo-integrated dental implants in partially edentulous patients has become a commonly accepted therapeutic option to restore dentitions, both aesthetically and functionally. In patients with reduced bone volume, tooth-to-implant connected prostheses have been described as a treatment option. In addition to a solely implant-supported fixed partial denture (FPD), tooth-to-implant connected prostheses have been proposed as a treatment alternative.[1] The force distribution of multiple tooth-supported and implant-supported prostheses is completely different. A direct correlation exists between the degree of flexion at the site of loading and the amount of force distribution to other members of the prosthesis. Micromovement produced by the periodontal fibres facilitates force distribution to all the root surfaces of the natural tooth abutments. The rigidity of the implant/abutment/prosthesis configuration concentrates the force at the crestal bone at the site of loading with limited distribution to the remaining implants.[2] Differential mobility concentrates the force distribution to the bone support of the most rigid members of splinted natural teeth or to the implants when they are united with natural teeth in a combined prosthesis, Implants always support the natural teeth and never the other way around.[3]

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Natural teeth with a healthy periodontium demonstrate a mobility of about 50–200 μm whenever a force of 0.1 N is applied. On the other hand, mobility of an Osseo integrated dental implant is less than 10 μm upon application of similar forces. The threshold for tactile perception between natural teeth and implants as abutments for FPD is significantly different.[4] Several studies have described clinical cases where FPDs are supported by a connection between implants and natural teeth. These studies indicated the possibility of connecting implants to natural teeth in a FPD with a relatively good prognosis. Many clinicians feel that the more rigid the attachment is between the prostheses, the greater the mutual support between the natural teeth and implants will be. This would be true if we were dealing with only natural teeth or only implants. When tooth-implant-supported prostheses must be combined, the method of attachment should be non-rigid this relieves stress to the implant configuration.[5] Therefore, a non-rigid attachment is recommended between a tooth-supported prosthesis and an implant-supported prosthesis when they are combined.[6] Finite element analysis has become popular with in the field of prosthetic dentistry because it provides useful analysis of mechanical and biological factors that have led to numerous improvements in clinical practice.[7] The change in the implant location and non-rigid connector can affect the stress within the tooth-implant supported fixed partial denture complex and the alveolar bone. Generated stress varies with the implant location. The goal of the present study is to analyze the stress distribution in a simulated environment of rigid and non-rigid tooth-implant supported fixed partial denture where implants were placed in a different location and non-rigid connector on the mesial side of the pontic with all other parameters being constant.

II. MATERIALS AND METHODS

Three-dimensional modelling

An edentulous atrophic mandible specimen was taken from the Department of Anatomy, The Oxford Dental college, Bangalore. A cone beam computed tomography (CBCT) of the atrophic mandible was taken at oral 3D diagnostics, Bangalore. The cross section of the mandible was obtained at equal intervals of 1mm. The CT scan of an edentulous mandible having a trabecular core of D3 bone surrounding 1mm thick cortical layer in the lower part was taken. The model was then exported in the STL format and was converted to a CAD model for further processing and analysis. HYPERMESH 11 software was used to convert 3D images into numerical models. Graphic pre-processing software ANSYS version 18.1 was used for creating the geometric configuration of the mandible.

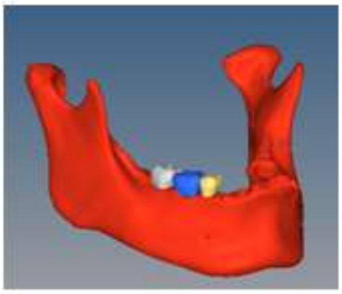

Fig 1. FEM model of mandible

A total of two models will be constructed with different implant (Bioline, Israel) location and non-rigid connector on the mesial side of the pontic in tooth- implant supported fixed partial denture. The respective abutments were selected: internal hex (3.75×13mm). The geometry of the implants and their components were provided by implant manufacturer (Bioline) and transformed to a 3D format.

A geometric model of metal ceramic frame work material was created by using SOLID EDGE version 19 software and then be inserted in the bone model. Three-dimensional model of the implant, abutment and bone models restored with implant supported fixed partial denture framework using ceramic - coated nickel chromium – titanium alloy framework materials[1]. Rigid and nonrigid partial fixed prostheses were both explored. An intracoronal attachment matrix (2.5 mm) that was positioned distally of the second right premolar and inserted into the pontic was used as the nonrigid connection.

The two models listed below were used to run the simulations:

1) MODEL-1: Second right molar (implant) and first right molar (pontic) are connected by a rigid connector, first right molar (pontic) and second right pre-molar (natural tooth) are connected by a non-rigid connector.
2) MODEL-2: Second right pre-molar (implant) and first right molar (pontic) are connected by a non-rigid connector, first right molar (pontic) and second right molar (natural tooth) are connected by a rigid connector.

The mesh is programmed to contain the material and structural properties (elastic modulus, Poisson's ratio and yield strength), which defines how the structure will react to certain loading conditions. The 3D models were exported to the Hyper Mesh version 11 software for mesh generation, leading to a virtual geometrical mesh arranged in a 3D manner. Each element was interconnected at a number of discrete points called nodes. The tetrahedral elements were adjusted for all structures with minimum and maximum sizes (0.15 to 0.7mm). Stress concentrations in areas of interest were manually refined to ensure the accuracy of the analysis. The displacement of each of these nodes was calculated to determine maximum compressive and tensile stress throughout the structure. All materials were considered isotropic, linearly elastic and homogeneous. Material properties were taken from the standard text book of dental materials and implantology, further were assigned to the elements and the software is enabled to identify it. The models were transferred through the solid works simulation program for finite element analysis and stress distribution investigation. The implants were considered fully osseointegrated to the peri-implant bone. The prosthetic framework and abutment interface were considered with a 0.3 frictional coefficient to better assess the prosthetic framework displacement. The load applied was divided equally on the mandibular posterior teeth among the second premolar (50N), first molar and second molar (100N).

MATERIAL	YOUNG'S MODULUS (Mpa)	POISSON'S RATIO
Titanium	110,000	0.33
Cortical bone	13,700	0.30
Trabecular bone	1,370	0.30

TABLE 1: Material property assigned to models.

The load applied was divided equally on the mandibular posterior teeth among the second premolar (50N), first molar and second molar (100N). The equivalent von Mises stress analyses was used to study implants, abutments, and frameworks. Maximum and minimum main stresses were done utilising graphical visualisation colour maps to observe the trabecular and cortical bone.

III. RESULTS

The minimum stress values are seen in the PDL are shown in Figure 3. when the implant was connected by nonrigid connector there was a distribution of maximum stress and there was no movement. The minimum stress distribution is seen in the model where the implant connected by a rigid connection and tooth connected by a nonrigid connection. The periodontal ligament was under constant tensile tension, while the apical region was under compressive pressures. This indicates possible intrusion of the tooth. In the model 2 there was better stress distribution, and the forces were annulled.

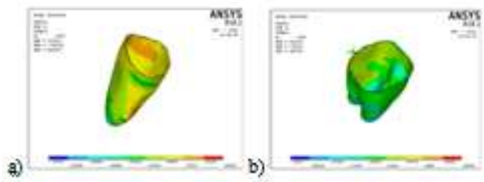

Fig 2. Minimum stress values at the periodontal ligament in different conditions: a) nonrigid connection, b) rigid connection

Implant

When implant is used by the rigid connection there was a higher incidence of compressive forces seen at the cervical region corresponding to the cortical bone. The implant connected by a nonrigid connector exhibited better maximum stress distribution. Minimum stresses occurred at the cortical bone with the lack of stress at the trabecular bone Figure 4.

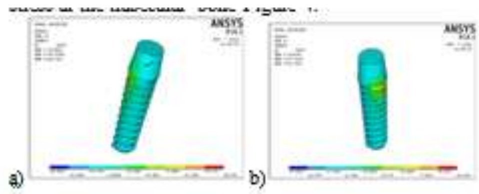

Fig 3. Maximum stress values at the implant in different conditions: a) rigid connection, b) nonrigid connection.

Bone

The von mises stress distribution is shown in fig 4. When the rigid connector was used in the both models, stress was predominant in the connector region of the implant, abutment/pontic area. When the nonrigid connector was used, there was high stress at the abutment region and an more stress in the connector present between the implants and abutment/pontic area.

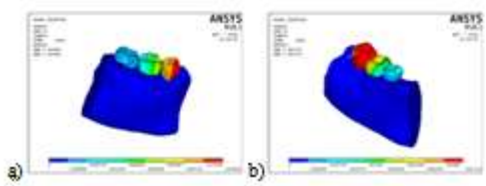

Fig 4. Von mises stress distribution: a) rigid connection, b) nonrigid connection.

IV. DISCUSSION

According to the current study, one of the most crucial aspects of Osseo integrated implants' performance is how they respond to the pressures placed on them. The stress brought on by incidental loads may have an impact on peri-implant bone remodeling. The current study assessed how much stress may be generated in a fixed partial denture supported by teeth and implants using two alternative connector types—rigid and nonrigid—and varied implant placements. The findings imply that the bio-mechanical behaviour of the rehabilitation was influenced by the implant placement type. However, rigid and non-rigid connections have an impact on the outcomes of the FEA method analysis.

FEA is a crucial technique for examining stress distributions in implants and their constituent parts. The peri-implant bone, the impact of biomechanical factors on the implant-bone interface, and the stress patterns in these regions are also studied using FEA. The interface and interactions between an implant and the surrounding osseous tissue can be simulated using FEA. The mechanical impact of occlusal pressures on implants and the peri-implant trabecular/cortical bone is examined using von Mises stress values. Failures happen when the von Mises stress values are higher than a metallic material's yield strength. The interpretation of the stress that develops within the metallic fixed partial denture material depends on this. A dental implant's surrounding bone is impacted by occlusal forces.

The present study showed the stress distribution pattern, generated by applying static vertical loading of 100N on molar and 50N on premolar in both the frameworks. The numerical values expressed the stress on the frameworks and revealed that the materials elastic modulus influenced the stress distribution in both the frameworks.

The overall stress was least within the tooth-tissue supported fixed partial denture (FPD) where the second right premolar (implant) is connected by a non-rigid connector to the second right molar (natural tooth). But the stress on the second right molar (natural teeth) is higher where it is connected by a rigid connector to the fixed partial denture. The overall stress was found to be greater in the fixed partial denture where second right molar (implant) is connected by a rigid connector to the second pre-molar (natural tooth) under static vertical loading. But the stress on the second right pre-molar (natural teeth) is less where it is connected by a rigid connector to the fixed partial denture.

Hence, in the current finite element study, an increase in the stress within the fixed partial denture was observed when the implant is connected to a tooth by a rigid connector and increase in the stress within the fixed partial denture when natural teeth is connected by a rigid connector due to minimum stress distribution.

These findings are in agreement with previous studies which suggested that the rigid connectors cause higher stress concentrations within the tooth-implant supported fixed partial denture than the non-rigid connectors due to their lesser deformation.

The limitations of the present study are it is an in silico, computerized method in which clinical conditions may not be completely replicated. In this study, 100% osseointegration was assumed. However, real-life osseointegration ranges between 40% and 60%. The results were obtained using linear analysis, and the PDL was assumed to be a viscoelastic material. Loads are applied unilaterally at specific locations. Misfits of structures under occlusal loads were not evaluated.

V. CONCLUSION

Within the limitations of the study, the following conclusions were drawn:

The stress was least within the tooth-tissue supported fixed partial denture (FPD) where the second right premolar (implant) and first right molar (pontic) are connected by a non-rigid connector, first right molar (pontic) and second right molar (natural tooth) connected by a rigid connector.

The results of the study concluded that regardless of the implant and the teeth location the stresses are higher within the framework and supporting structures of the fixed partial denture when connected by a rigid connector. The non-rigid connector demonstrated better load distribution, within an absence of tension in the trabecular bone in both prostheses. Finally, regardless of the implant and teeth location, there was a greater tendency toward compressive loads at the crestal area when a rigid connector is used in both prostheses.

The rigid connections in tooth-implant supported fixed partial denture are responsible in causing higher stresses within and the supporting structures of the framework than the non-rigid connections.

Generally, least stress and least deformation are desirable for the safety of the implant supported prosthesis. So, by observing the stress and deformation patterns in the tooth-tissue supported fixed partial denture framework where the implant connected by a non-rigid connector to the teeth showed the most favourable biomechanical behaviour.

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