ORIGINAL RESEARCH

Comparison of Stress Distribution in Fixed Partial Prosthesis Restored with Different Combination of Support: A Finite Element Study

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Abstract

Aim: This study was conducted to evaluate the distribution of stress in the bone around the natural tooth, endodontically treated tooth having post and core, and implant as an abutment in different combinations in fixed partial prosthesis using two-dimensional finite element analysis (FEA).

Materials and methods: Six models were simulated using ANSYS Modeller19. All six models were divided into 12 zones and 4 lines, and stress values were calculated and compared. The study combinations were – tooth supported fixed partial prosthesis, fixed partial prosthesis having the combination of tooth and post- and core-treated tooth, fixed partial prosthesis with the combination of tooth and implant, fixed partial prosthesis having the combination of implant and post- and core-treated tooth, fixed partial prosthesis with the combination of post- and core-treated tooth on both sides, and fixed partial prosthesis having the combination of implant on both sides.

Result: On comparing the stress values, the maximum stress value was observed in fixed partial prosthesis having the combination of implant on both sides (306.2434 MPa) followed by Model 4 (223.1255 MPa), Model 3 (154.3952 MPa), Model 5 (136.9041 MPa), Model 2 (116.2034 MPa), and least stress seen in Model 1 (99.6209 MPa), and minimum in tooth supported fixed partial prosthesis (99.6209 MPa).

Conclusion: This study concluded that stress concentration in bone was maximum when the implant was used as an abutment in fixed partial prosthesis. The least stress was seen in bone around the natural tooth due to the dampening effect of the periodontal ligament. Further, the modulus of elasticity of a post acts as a vital parameter in the distribution of stress in post- and core-treated tooth.

Clinical significance: The stress concentration in the bone around the abutments affects the longevity of the prosthesis, hence, the clinically appropriate combination of the abutments should be considered for a fixed partial prosthesis.

Keywords: Cancellous bone, Composite, Cortical bone, Modulus of elasticity, Stainless steel, Titanium.

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Introduction

Fixed partial prostheses (FPP) are one of the most frequently carried-out treatment modalities in prosthodontics with proven clinical reliability.[1–3] In cases of rehabilitation, we encounter a large number of clinical scenarios, such as edentulous spaces, unavailability of sufficient bone dimension for placement of implants, failure of an implant osseointegration, and endodontically treated tooth with a little remaining crown. Often, to carry out fixed treatment modalities, it becomes necessary to connect natural tooth, osseointegrated implant, and endodontically treated tooth with post and core as abutments. However, the thought of whether or not to join the implant with the tooth and the way to combine them still remains a matter of controversy. Such a combination of abutment supports leads to a series of physiological and engineering problems, such as intrusion of abutment tooth, loosening of the fixture, fracture of implant or tooth or prosthesis, and decementation of restoration, which is due to differences in their biomechanical fundamentals.[3,4] Prosthetic alternatives suggested by various studies for FPP connecting bio-integrated implants and natural teeth include rigid connectors or nonrigid connectors between the implant and natural tooth or elements that allow prosthesis movement attached to implants.[5–10] Clinical results obtained from various studies showed that the outcome is acceptable with each of these treatment modalities, but the most acceptable technical design is still undefined.[5,11–15] Thus, success and longevity of the FPP depend upon the stress distribution in its various components and osseous tissue. However, there has been inadequate research focusing on the comparison of bone stress distribution in different combinations of supports in FPP, especially implant and endodontically treated tooth with post and core, as the modulus of elasticity of post also affects stress distribution in the bone. Finite element analysis (FEA) is used to analyze the stress in dental materials and prosthetic design. Finite element analysis precisely analyzes the magnitude and distribution of stress at any particular point under a variety of simulated clinical situations.[1] A finite element study has many advantages as compared with the studies on the real model, such as experiments being repeatable, no ethical considerations, and as per requirements, the study

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Table 1: Mechanical properties of the materials or structures used in the current study

Anatomical structures	*Young's modulus (GPa/MPa)*	*Poisson's ratio*
Cortical bone	13,700 MPa	0.30[20]
Cancellous bone	1,370 MPa	0.30[20]
Dentin	18.6 GPa	0.31[17]
Periodontal ligament	0.0000689 GPa	0.45[17]
Gutta-Percha	0.069 GPa	0.45[17]
Glass ionomer cement	7.56 GPa	0.35[21]
Porcelain	69 GPa	0.28[22]
Stainless steel	200 GPa	0.33[4]
Ni–Cr alloy	203 GPa	0.30[17]
Titanium implant	110 GPa	0.35[23]
Composite	12,000 GPa	0.30[18]

Table 2: Details of finite element mesh used for each model

Models	*Numbers of nodes*	*Numbers of elements*
1. Tooth-supported fixed partial prosthesis	93,632	29,738
2. Fixed partial prosthesis having the combination of tooth and post- and core-treated tooth	94,329	29,863
3. Fixed partial prosthesis having the combination of tooth and implant	94,412	30,075
4. Fixed partial prosthesis having the combination of implant and post- and core-treated tooth	92,474	29,594
5. Fixed partial prosthesis having the combination of post- and core-treated tooth on both sides	94,715	29,770
6. Fixed partial prosthesis having the combination of implant on both sides	92,192	29,892

design can be changed and modified. This study was aimed to comparatively evaluate the distribution of stress in the bone around various combinations of FPP using abutments such as a natural tooth, endodontically treated tooth with post and core, and implant.

Materials and Methods

The FEA was performed using the ANSYS Modeler 19 software. The six models were: Model 1 – tooth supported fixed partial prosthesis, Model 2 – fixed partial prosthesis having the combination of tooth and post- and core-treated tooth, Model 3 – fixed partial prosthesis having the combination of tooth and implant, Model 4 – fixed partial prosthesis having the combination of implant and post- and core-treated tooth, Model 5 – fixed partial prosthesis having the combination of post- and core-treated tooth on both sides, and Model 6 – fixed partial prosthesis having the combination of implant on both sides. In order to minimize the variability in the study, all physical parameters were assumed to be isotropic and homogeneous with similar linear elasticity. This was done to concentrate on the comparative evaluation of stress of the FPP rather than analyzing the effect of the other variables.[10] The physical properties used in the calculation were obtained from the literature (Table 1). In all the six models, the following criteria were standardized.[16–23]

Natural Tooth and Endodontically-treated Tooth with Post and Core

The dimension of the permanent mandibular 2nd premolar and 2nd molar was according to Wheeler's dental anatomy.[17] The periodontal ligament thickness of 0.25 mm was modeled.[18] In the analysis, a single value of elasticity was considered for the periodontal ligament. Cortical bone thickness of 1.5 mm and cancellous bone of 18.5 mm thickness were modeled in two layers.[16] The thickness of the embedded portion of the modeled post and core was 1.4 mm cervically and 0.6 mm apically, and the length of the post and core for premolar was 11.5 mm, and for molar was 10 mm. The thickness of the composite core was 2.5 mm.[19]

Implant

The dimension of an implant in the permanent mandibular 2nd premolar region was 13 mm × 4 mm and in the mandibular 2nd molar region was 11 mm × 4.5 mm.

Fixed Partial Prosthesis

Metal coping thickness of 0.5 mm and overall porcelain thickness of 1 mm with additional 0.5 mm on the cusp was standardized for porcelain fused to metal restoration.[20] Further, the connector between the retainer and pontic was standardized to a vertical thickness of 3 mm.[16] The cement-layer thickness of 0.1 mm between the retainer and abutment was taken.

Creation of FEM Model

For each model, the boundary conditions were set to simulate the physiological condition of the mandible. Using the above specification, six two-dimensional models were simulated using ANSYS Modeller19. Quadrilateral elements were meshed to simulate all models with their supporting structures. The number of nodes and elements for each model is shown in Table 2. All six models were divided into 12 zones and 4 lines for stress analysis.

For Models 1, 2, and 5

Zone 1 – mesioalveolar crest of premolar, zone 2 – mesio middle third of premolar root, zone 3 – mesioapical third of premolar root, zone 4 – distoapical third of premolar root, zone 5 – disto middle third of premolar root, zone 6 – distoalveolar crest of premolar root, zone 7 – mesioalveolar crest of molar, zone 8 – mesio middle third of mesial root, zone 9 – mesio middle third of mesial root of molar, zone 10 – disto apical third of distal root of molar, zone 11 – disto middle of distal root of molar, and zone 12 – distoalveolar crest of molar.

For Model 3

Zone 1 – mesioalveolar crest of implant, zone 2 – mesio middle third of implant, zone 3 – mesioapical third of implant, zone 4 – distoapical third of implant, zone 5 – disto middle third of implant, zone 6 – distoalveolar crest of implant, zone 7 – mesioalveolar crest of molar, zone 8 – mesio middle third of mesial root root, zone 9 – mesio middle third of mesial root of molar, zone 10 – disto apical third of distal root of molar, zone 11 – disto middle of distal root of molar, and zone 12 – distoalveolar crest of molar.

For Model 4

Zone 1 – mesioalveolar crest of premolar, zone 2 – mesio middle third of premolar root, zone 3 – mesioapical third of premolar root,

Table 3: Values of von Mises stress along lines 1, 2, 3, and 4 along with total stress

Sl no.	*Models*	*Line 1 MPa*	*Line 2 MPa*	*Line 3 MPa*	*Line 4 MPa*	*Total MPa*
1.	Tooth supported fixed partial prosthesis (Fig. 1)	18.1727	31.0046	39.4686	10.975	99.6209
2.	Fixed partial prosthesis having the combination of tooth and post- and core-treated tooth (Fig. 2)	19.0047	37.6616	47.1163	12.4208	116.2034
3.	Fixed partial prosthesis having the combination of tooth and implant (Fig. 3)	25.6889	63.3303	46.0033	19.3127	154.3952
4.	Fixed partial prosthesis having the combination of implant and post- and core-treated tooth (Fig. 4)	12.8308	31.7697	115.441	63.084	223.1255
5.	Fixed partial prosthesis having the combination of post- and core-treated tooth on both sides (Fig. 5)	13.566	50.9782	38.529	33.8309	136.9041
6.	Fixed partial prosthesis having the combination of implant on both sides (Fig. 6)	49.9554	118.184	93.567	44.537	306.2434

zone 4 – distoapical third of premolar root, zone 5 – disto middle third of premolar root, zone 6 – distoalveolar crest of premolar root, zone 7 – mesioalveolar crest of implant, zone 8 – mesio middle third of implant, zone 9 – mesio middle third of implant, zone 10 – disto apical third of implant, zone 11 – disto middle of implant, and zone 12 – distoalveolar crest of implant.

For Model 6

Zone 1 – mesioalveolar crest of implant, zone 2 – mesio middle third of implant, zone 3 – mesioapical third of implant, zone 4 – distoapical third of implant, zone 5 – disto middle third of implant, zone 6 – distoalveolar crest of implant, zone 7 – mesioalveolar crest of implant, zone 8 – mesio middle third of implant, zone 9 – mesio middle third of implant, zone 10 – disto apical third of implant, zone 11 – disto middle of implant, and zone 12 – disto alveolar crest of implant.

Loading

Axial static occlusal load of 100 N was applied on the mesiobuccal and distobuccal cuspal inclines of the mandibular 1st and 2nd molar and buccal cusp tip of the 2nd premolar in all six models. The related data were recorded, tabulated and analyzed. The specific colors have been mentioned in the figures to facilitate the observation of the stress patterns. In FEA study, the sample size was small, so statistical analysis was not applicable.

Result

The value of stress was recorded in each zone for comparison of stress distribution. Line 1 – zones 1 + 2 + 3, line 2 – zones 4 + 5 + 6, line 3 – zones 7 + 8 + 9, line 4 – zones 10 + 11 + 12. The values of all 12 zones along the four lines were added to calculate the total stress of each model, and these values were comparatively evaluated, as shown in Table 3.

The maximum stress was observed in Model 6 (306.2434 MPa), followed by Model 4 (223.1255 MPa), Model 3 (154.3952 MPa), Model 5 (136.9041 MPa), and Model 2 (116.2034 MPa), and least stress was seen in Model 1 (99.6209 MPa).

Discussion

This research was undertaken to comparatively calculate the distribution of stress in bone in simulated six models using two-dimensional FEA. The FEA is a mathematical method of evaluating the stress, strain, and deformation of a structure. Finite element analysis is a widely accepted modern tool that uses a noninvasive method to analyze the influence of biomechanical stresses in the biological system. It allows establishment of location, magnitude, direction of force, and points on which stress can be measured. The material to be studied fragmented into finite elements joined together by nodes. Various parameters such as type, arrangement, and total number of the elements affect the accuracy of the result.

Functional loading causes strain resulting in the remodeling of bone around abutments. Functional stresses ranging from 200 to 700 psi are required to maintain the existing alveolar bone height.[21,22] It has been observed that stresses outside this range are likely to result in bone tissue degeneration. If the stresses are too

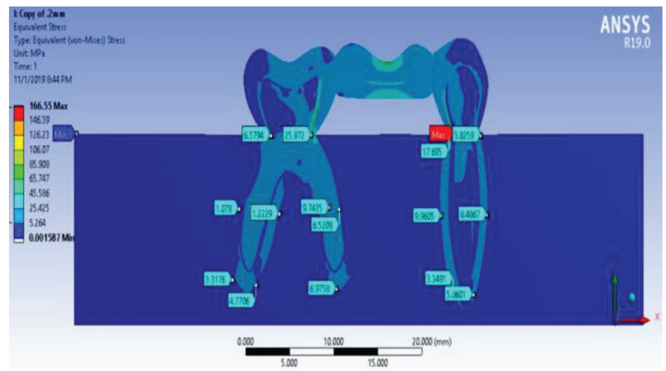

Fig. 1: Tooth supported fixed partial prosthesis

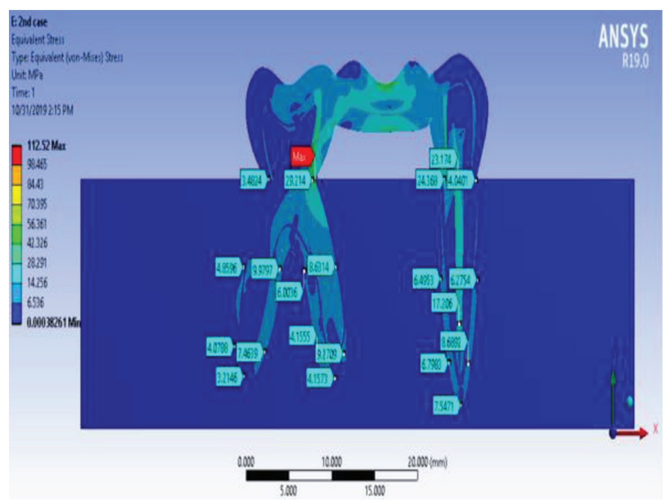

Fig. 2: Fixed partial prosthesis having the combination of tooth and post and core treated tooth

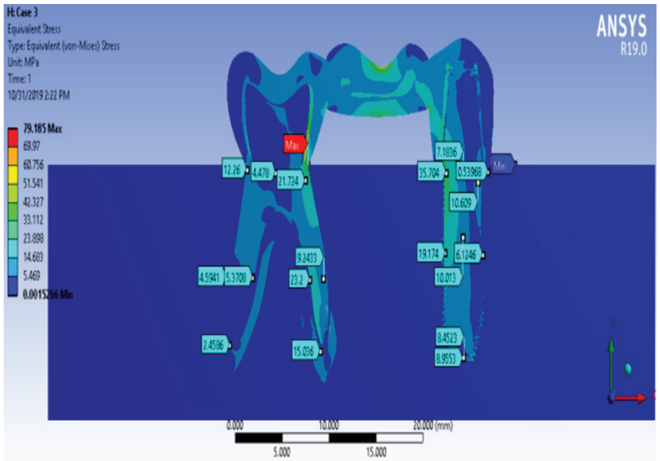

Fig. 3: Fixed partial prosthesis having the combination of tooth and implant

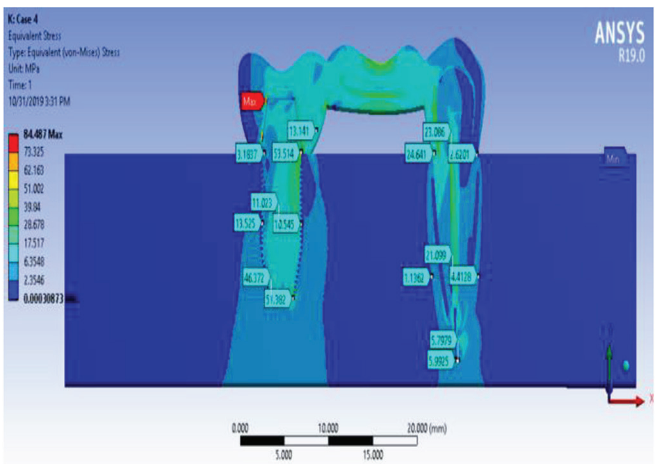

Fig. 4: Fixed partial prosthesis having the combination of implant and post and core treated tooth

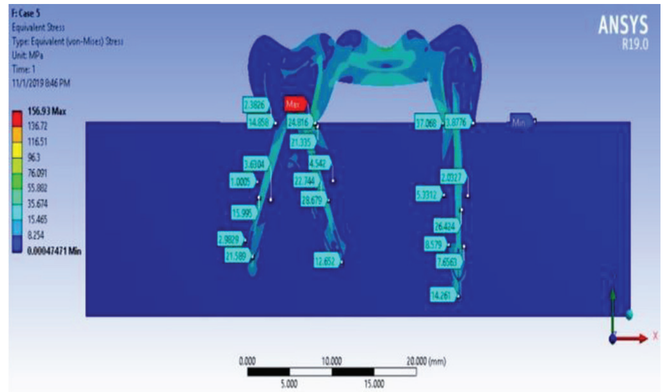

Fig. 5: Fixed partial prosthesis having the combination of post and core treated tooth on both sides

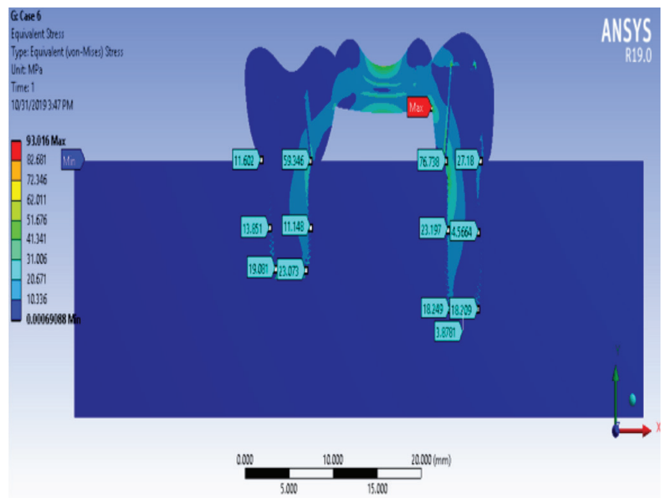

Fig. 6: Fixed partial prosthesis having the combination of implant on both sides

low, bone atrophy occurs. Hence, long-term success of fixed partial prosthesis depends upon proper biomechanical consideration for fixed partial prosthesis designing.

According to Laufer et al.,[23] Pesun et al.,[24] and Suansuwan and Swain,[25] the connection of the natural tooth and implant must not be considered as the first option for rehabilitation. The mobility characteristics of the natural tooth are between 50 and 200 micrometers while osseointegrated implant mobility is less than 10 micrometers.[4] When using a combination of natural teeth and osseointegrated implant as an abutment in a fixed partial prosthesis, the fundamental difference in mobility between the implant and natural teeth leads to potential risk for biomechanical complications such as intrusion of a natural tooth, loosening of a screw, and crestal bone loss.[26] These observations coincide with the results obtained in our study.

The results of our study show maximum stress concentration in Model 6 (306.2434 MPa) followed by Model 4 (223.1255 MPa). This result was obtained due to the absence of periodontal ligament around an implant leading to rigid connection between the implant and bone. Further, the modulus of elasticity of cortical bone is more as compared with cancellous bone. This finding is similar to the FEA study conducted by Kumar et al.,[27] who stated that the cortical bone is more resistant to deformation and will bear more load as compared with cancellous bone due to the high elastic modulus of cortical bone. The micromovements of the implant in bone due to osseointegration are very few and are not effectively distributed to other components of the prosthesis. This observation is similar to that of Weinberg and Kruger[28] who observed force distribution in implant-supported prosthesis as compared with tooth-supported fixed partial prosthesis. He concluded that force concentration at the crestal bone around the osseointegrated implant is more as the bone is stiff and offers no flexion.

Similar results were obtained by Zhang et al.[29] who stated that inclined forces produced the shear force and bending movement of the implant leading to stress concentration at the implant's neck and bone contact area.

Next, more stress concentration was observed in Model 3 (154.3952 MPa) followed by Model 5 (136.9041 MPa). When the implant and natural tooth are connected, physiological movement of the natural tooth causes bending momentum in the bone, leading to more stress concentration in peri-implant bone. This is due to the tendency of the tooth to depress in the alveolus under axial load.[30] The studies Menicucc et al.,[30] Misch and Ismail,[31] Cruz et al.,[32] Naveau and Pierrisnard,[33] Lin et al.,[34] and Jafarian et al.,[35] also showed that the absence of PDL increased the susceptibility of occlusal loading of the implant.

The least stresses were observed in Model 2 (116.2034 MPa) followed by Model 1 (99.6209 MPa). This may be due to the high modulus of elasticity of the stainless steel post as compared with the dentinal wall around it, leading to stress concentration within the post. Studies done by Kaur et al.,[36] Toksavul et al.,[37] and Bessone and Fernandez[38] also showed that the modulus elasticity of restorative material for teeth and root dentine should resemble for the uniform distribution of exerted shear forces. Creating the 2D sketches of the 3D fixed partial prosthesis is the most efficient and simplest way to construct solid models.[39] The limitations of this study were FEA is a computerized *in vitro* study in which clinical condition may not be replicated completely. Stress analysis is conducted usually under static loading and the mechanical properties of the materials are considered homogeneous, isotropic, and linearly elastic although in reality it is not.

Conclusion

Within the limitation of this study, it can be concluded that stress concentration is more around the implant, when used as abutment, as compared with the natural tooth due to rigid connection between alveolar bone and implant which results in limited mobility of the implant. The periodontal ligament's visco-elastic property plays a vital role in reducing stress and damping the occlusal load effectively. Further, it is advisable to use restorative materials with Young's modulus similar to natural tooth structure. Further studies should focus on developing such a connector between the natural tooth and implant, which properly distributes stress.

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