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INFLUENCE OF DIFFERENT DESIGNS AND MATERIALS ON LOAD-BEARING CAPACITY OF THE FIXED DENTAL PROSTHESIS; A FINITE ELEMENT ANALYSIS

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ABSTRACT

Objective: This study directed to compare different tooth-supported fixed dental prostheses "FDP" designs (pier abutment and cantilever designs) and their effect on stress distribution through using the restorative materials (PEEK, Zirconia, and Porcelain fused to metal)**. Materials and methods**: Three dimensional (3D) finite element models were constructed for both designs: pier abutment design and cantilever design. Different upper fixed dental prostheses, including the abutments (upper canine, premolar, and molar) and other components such as retainers, connectors, pontic, and gingiva were created in "Autodesk inventor" version 8 and then exported as SAT file. These components are assembled in an ANSYS environment (computer Intel Pentium Core 2 Duo. The proposed FDP materials are; Porcelain fused to metal (PFM), Zirconia, and Poly-Ether-Ether-Ketone (PEEK). Three finite element models were constructed. Pier abutment designs (conventional rigid connector fixed-fixed five units pier abutment) and cantilever designs (2 units & 3 units design). The study performed a total of nine runs (stress analysis and stress distribution). When the vertical loading was applied, three runs were done for each model (PFM, Zirconia, and PEEK restorative materials). **Results**: Data were represented as Von Mises stress for the maximum value of stress. PFM, and Zirconia FDP behavior were comparable, while the PEEK one transferred much more load to FDP components and the underneath structures. Moreover, total deformation of bone was increased when using PEEK as "FDP" than with Zirconia, and PFM. **Conclusions:** Conclusions: PEEK was liable to higher deformation and delivered unacceptable stress to surrounding vital structures such as the bone.

KEY WORDS: PEEK, cantilever, pier abutment, finite element analysis

INTRODUCTION

Missing teeth and coronal tooth structures have been replaced with fixed dental prostheses (FDP). For decades, metal-ceramic FDP has been used to replace missing teeth. They do, however, have a number of drawbacks, including metal substructures that reduce light permeability, porcelain veneer chipping or color change, and metal alloys that are allergic and poisonous [(1)].

To overcome the drawbacks of metal ceramics, ceramic materials have been developed. Ceramic restorations provide better aesthetics and biocompatibility than metal restorations [(2)]. Due to their great flexural strength, zirconia-based restorations are the most widely utilized in fixed dental prostheses (FDPs) [(3-4)]. Furthermore, multiple studies have shown that zirconia aesthetic restorations can be employed as an alternative to

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metal-supported restorations, particularly in anterior maxillary rehabilitation [5-8]. Zirconia (Zr) has the optimum characteristics for dental applications when stabilized with Yttrium oxide [9]. Zirconia restorations, on the other hand, are prone to an unfavorable phase change at ambient temperature, known as (low-temperature degradation). This mechanism may result in yttrium loss, distorted stability of Zirconia's tetragonal phase, uncontrolled tetragonal-monoclinic changeover, and surface roughness. Finally, mechanical qualities and restoration strength may be affected [10-11].

PEEK material is a modern material attracting interest for use in dentistry. Due to the high elasticity modulus, there is increasing use of the material in implantology and endodontics [12-14]. It is a good alternative to metal ceramics since it does not rust when it comes into contact with other metals in the mouth. Furthermore, due to its hardness and strong wear resistance, this material can compete with other dental materials [15].

The mesial and distal abutments provide complete support for conventional FDP that replaces one or more missing teeth. A cantilever FPD, on the other hand, is supported from one end by one or more abutments [16]. Stresses inside prosthetic components are difficult to evaluate clinically. It is necessary to examine the stresses within the prosthesis and surrounding tissues in order to determine the success of any dental prosthesis [17].

One of several approaches for assessing the mechanical properties of structures is finite element analysis (FEA) [19-24]. The stress distribution through various prosthetic designs, materials, and surrounding tissues has been predicted using FEA. It can also recreate most dental structures in three dimensions, with different forms and loading characteristics [18, 26-30].

The null hypothesis of this study is that there is no a difference in stress distribution between different tooth-supported fixed dental prostheses designs (pier abutment and cantilever designs), as well as there is no difference in stress distribution between the restorative materials in the study (PEEK, zirconia, and Porcelain fused to metal).

MATERIAL AND METHODS

Materials:

Materials used in this study and their composition. Table (1).

Materials	Chemical composition
Zirconia	$ZrO_2+HfO_2+Y_2O_3 \geq$ (99.9%), $Al_2O_3 \leq$(0.005%), $Fe_2O_3 \leq$ (0.02%), Other oxides ≤ (0.2%).
PEEK	(-C6H4-OC6H4-O-C6H4-CO-)n; is a semi-crystalline linear polycyclic aromatic polymer reinforced by ceramic filler and has a grain size of 0.3 to 0.5 µm
Porcelain fused to metal	1. Ni-Cr Alloy:Ni 62%, Cr 22%, other (Mn, N, Nb, Fe) < 1% 2. Ceramic: Glass (silica) based ceramic

Methods

The following three finite element models were created and analyzed:

Step 1: Modelling

The FDP, mucosa, cements layer, and cortical bone finite element model components were produced in "Autodesk inventor" version 8 (Core i7, 5500U CPU processor, 2.4 GHz, 6 GB RAM) and then exported as SAT files. In an ANSYS environment, the components were assembled (computer Intel Pentium Core 2 Duo, processor 3.0 GHz, 4.0 GB RAM).

Model 1: The maxillary second molar (upper 7) is assumed to be missing, with the maxillary first molar serving as an abutment tooth.

Model 2: The maxillary second molar (upper 7) is assumed to be missing, with the maxillary first molar and second premolar serving as abutment teeth.

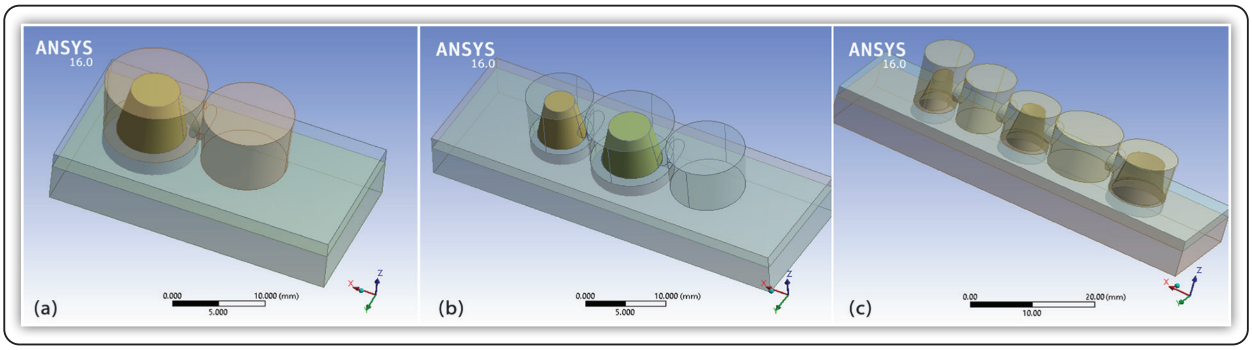

FIG (1) Shows the construction of geometric models for cantilever designs; a) 2 units design, b) 3 units design. Pier abutment design; c) conventional fixed-fixed design.

Model 3: The maxillary first premolar (upper 4) and maxillary first molar (upper 6) are assumed to be missing in this model. Abutments are the maxillary canine (upper 3), maxillary second premolar (upper 5), and maxillary second molar (upper7). Figure (1).

Step 2: Material definition

In this step, the material properties were defined. These parameters vary depending on the type of analysis required, such as Young's modulus and Poisson's ratio. Material properties were chosen and imported from a finite element tool library. Table (2).

TABLE (2) Material properties used in the finite element model.

Material	Modulus of elasticity [MPa]	Poisson's ratio
Cortical bone	13,600	0.35
Dentine	15,000	0.31
Gingiva	680	0.45
Glass Ionomer	12,000	0.25
Ni-Cr	205,000	0.33
Porcelain Fused to Metal (PFM)	149,450	0.34
Zirconia	200,000	0.31
PEEK	5,100	0.40

Step 3: Meshing

Geometry was subdivided into elements, which were smaller and simpler shapes. Nodes were used to connect the elements. This step was performed automatically by ANSYS to save end-user time and effort.

Step 4: Loads and boundary conditions

A single loading condition of 150N on the canine, 250N on each premolar, and 350N on each molar was applied to each flat occlusal model. Each tooth's palatal area (functional area) was subjected to vertical loading[11]. As a boundary condition in each model, the lowermost level of the bone was assumed to be fixed in three dimensions as a boundary condition. A commercial multipurpose finite element software package was used to do the linear static analysis on a DELL Inspiron 5500 laptop (ANSYS Workbench version 16.0).

Step 5: Analysis (Solution):

A total of nine runs (analyses) were performed, as three runs per fixed dental prosthesis design were done when the vertical loading was applied. Linear static analysis was performed on a personal computer.

Step 6: Post-processing of mesh

FEM software includes some kind of indicator that tells the user if the solution was successfully finished. These components were meshed using ANSYS 3D solid element (SOLID187), which has three degrees of freedom (translation in main axes directions in "x-, y- and z-axes"). Figure (2).

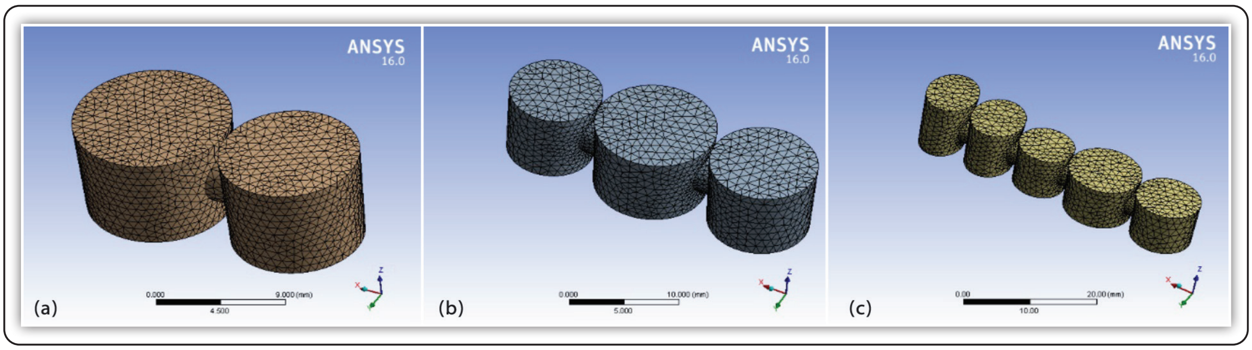

FIG (2) Shows the Post-processing of mesh models for cantilever designs; a) 2 units design, b) 3 units design. Pier abutment design; c) conventional fixed-fixed design.

RESULTS

The ANSYS software was used to import the built finite element models as well as the vertical loads. The displacement (total deformation) and stress distribution were investigated in these models. The maximum displacement contours (deformation), maximum Von Mises (yielding of materials under complex loading from the results of uniaxial tensile tests.), and stress distribution in fixed dental prostheses, abutments, and alveolar bone in the x, y, and z axes were obtained.

Cantilever design: Model 1 (2-unit cantilever); Both PFM and Zr fixed dental prosthesis (Zr FDP) behaved similarly, but the PEEK prosthesis transferred more laod to the underlying structures, increasing bone stresses by roughly five times (from 21.8 to 105 MPa). On the other hand, the Von Mises stress that appears on the FDP body was almost the same for three materials (about 271 MPa). For PFM and Zr FDPs, this value appears to be acceptable, but it appears to be relatively high for PEEK, producing increased deformation. This meant that the bone stress under the PEEK material was higher than the yield of bone. Furthermore, the PEEK material improved overall bone deformation by roughly 300%. When other abutments were added to model 2 (3 units cantilever), the amount of stress applied to bone decreased by roughly 25% (from 104.9 to 81.7 MPa). The tension placed on the FDP body by Von Mises was practically identical (about 225.3MPa). This value appears to be appropriate for PFM and Zr FDPs, but it appears to be relatively high for PEEK prosthesis.

Pier abutment design:

Model 3 (conventional fixed-fixed rigid connector design); PFM and Zr FDPs behavior were comparable, while the PEEK prosthesis transferred much more load to the Supporting structures to raise the stresses on bone by about four times (from 25.4 to 93.7MPa) on bone. On the other hand, Von Mises stress appeared on the FDP body itself is nearly the same (of order 297MPa. This value seems acceptable for PFM and Zr FDPs, but it looks relatively high for PEEK prosthesis. Figure (3) & (4).

In a brief, data from three restorative materials showed that Von Mises stress was considered a maximum value. The PFM and Zr FDP behaviours were similar, but the PEEK prosthesis transferred more load to the underneath structures.

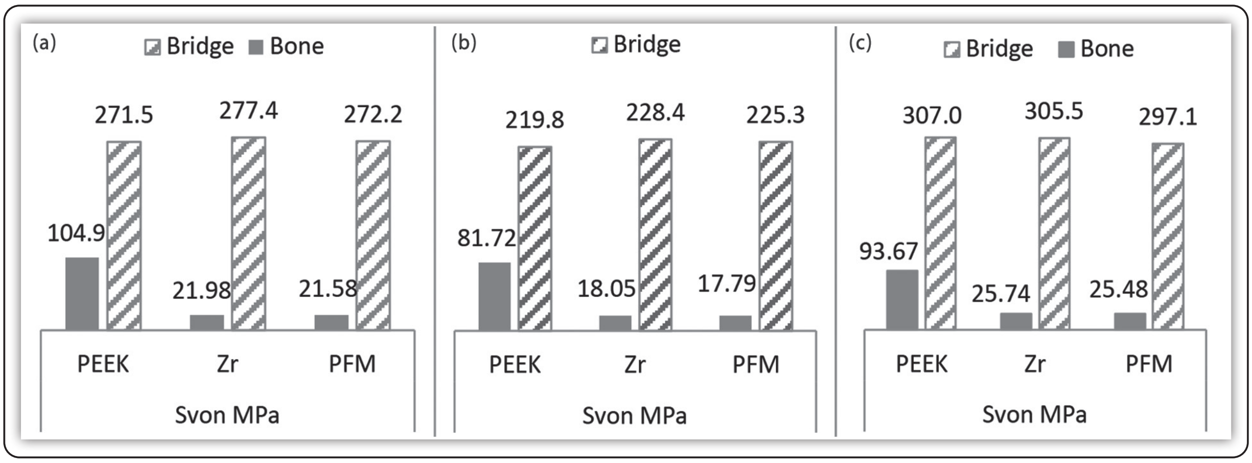

FIG (3) Von Mises stress in MPa for cantilever design; A) 2 units design, B) 3units design. Von Mises stress in MPa for pier abutment; C) conventional fixed-fixed design.

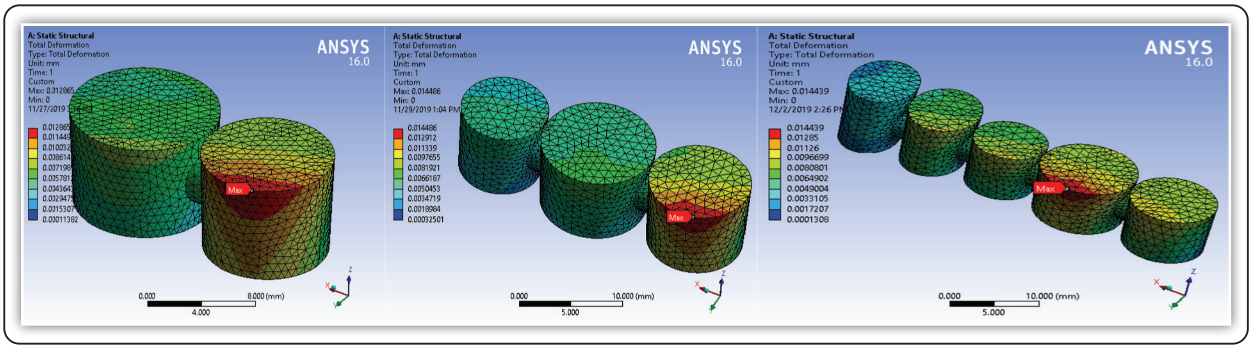

FIG (4) Total deformation values in millimeters for FDPs, abutments, and bone in different designs.

DISCUSSION

Finite element analysis (FEA) is a numerical method of analysing stresses and deformations in various structures. In the dentistry area, finite element analysis (FEA) has the potential to solve complicated biomechanical problems where conventional study approaches are insufficient. [8,17,18] In addition, FEA is utilised in the design phase to simulate the possibility of structural failure. The use of traditional in-vitro or in-vivo specimens is less needed with FEA. It also avoids the requirement for a large number of test teeth. As in other research, FEA used powerful software called "ANSYS software" to gain a deeper knowledge and detailed explanation of the biomimetic features of various restorative materials [4, 8, 11, 25].

According to the results of the current study, this null hypothesis was rejected. Because other critical aspects such as loading condition (location, amount, and direction of load) and preparation design may affect stress concentration, all models in this investigation were built with flat non-anatomical occlusal surfaces [4]. Furthermore, this design was in line with earlier research on single or multi-unit FDPs [4,11]. The designs were documented and accepted in both anatomical and non-anatomical forms [4, 11, 16]. The applied loads in this investigation (150N, 250N, and 350N) were near to the maximal occlusal load of healthy people, which ranged from 597 N to 847 N. [4, 30].

For FDP fabrication, porcelain fused to metal (PFM) has long been considered the gold standard. The demand for biocompatibility and aesthetic dentistry, on the other hand, encourages the marketing of novel items. PEEK could be a viable replacement for metal-based restoration. Where, in addition to exceptional mechanical and biological properties, its modulus of elasticity is similar to that of bone and dentin (15-18). Zirconia ceramic could be used as an alternative to metal-based restorations. It is a nontoxic, biocompatible substance with good mechanical qualities for both soft and hard tissues(6-11). The stress distribution may be affected by materials with varying elastic moduli. As a result, three different types of restorative materials were tested to see how they affected stress distribution on nearby structures.

PEEK materials had stress values that were equivalent to PFM and Zirconia in this study. It was, however, subjected to greater distortion and placed an unacceptable amount of stress on the surrounding bone. The reason why PEEK drives unacceptable stress to bone and gingival is due to the fact that it has a lower modulus of elasticity. Because PEEK has a lower modulus than other materials, it may be subjected to more bending, which could have a negative impact on the abutment and surrounding structures (bone & gingiva). Furthermore, three-unit cantilever prostheses reduced bone stress and strain deformation compared to two-unit cantilever prostheses, where the expanded abutment may resist stress better than a single abutment.

This explanation was consistent with prior research, which found that FDPs composed of high-modulus-of-elasticity materials protect tooth structures better than those made of resilient or resinous materials (low-modulus-of-elasticity materials)(4, 11). Porcelain, which has a high elastic modulus, displayed higher stress levels inside the material but only transferred a little amount of stress to the tooth structure (4).

The five-unit prosthesis with rigid connectors (five-unit pier abutment design with conventional fixed-fixed) caused less stress, according to the findings of this study. The pier abutment experienced more stress and deformation than the terminal abutments, as well as around the zones of a rigid connector. The stress and distortion of the alveolar bone surrounding the pier abutment were extremely significant. This study confirmed the findings of a prior study (17).

CONCLUSIONS

Within the limitation of this study, the following conclusion was drawn. PEEK is liable to higher deformation and delivered unacceptable stress to bone and gingiva than PFM and Zr FDP. As a result this may cause fatigue failure by time. It is recommended to avoid using PEEK material with long span fixed dental prothesis designs.

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