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RESEARCH

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Assessment of different materials used for fabrication of fixed free fixed dental prostheses: finite element analysis

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Abstract

Background This research assessed three materials to be used in the fabrication of fixed free fixed dental prosthesis using finite element analysis. Total deformation, Von Mises stress maximum amounts and sites on both the bone, and the fixed dental prosthesis body were compared.

Methods 3D finite element model was made for the tested fixed dental prosthesis and a contact scanner was used. A fixed free dental prosthesis was made restoring the maxillary first premolar, where second premolar with first molar were the supporting abutments that were scanned. Porcelain fused to metal, CEREC Tessera (Dentsply Sirona) and Poly-Ether-Ketone-Ketone were assessed as fixed free dental prosthesis materials. Cement thickness was adjusted to 40 microns. 100 N vertical load was applied to the central fossa of the pontic in the model.

Results The deformations in this study were within the acceptable range except with the PEKK fixed free prosthesis. Tessera showed better results than the porcelain fused to metal as the more elastic modulus allows for absorption of energy from loading.

Conclusions Purely used PEKK is not recommended for fixed free dental prosthesis. Low stiffness fixed dental prosthesis material helps in transferring low amount of load to the underneath tissues.

Keywords Fixed free, Prosthesis, Porcelain fused to metal, Tessera, PEKK

Background

Hollywood smile represents the dream of millions nowadays. When you look at a photo at the first glance you notice the smile firstly. Restoration of missing teeth is the door key in prosthodontics nowadays. When patients lose their valuable teeth they go urgently to dental clinics seeking the comfortable and feasible treatment to restore function as well as aesthetics (Demirci et al. 2022).

The fixed free dental prosthesis is a type of restoration where the supporting abutments are only from one side while the extension on the other side.

Actually cantilever bridge design solves the serious problems of complicated missing teeth and represents a money saving option alternative to dental implants. To summarize a better smile could be built using dental cantilever bridges. However, to ensure success and longevity of these designs the appropriate dental material should be carefully selected (Kharakh et al. 2020).

Several materials have appeared in dental applications for fabrication of fixed restorations. One of these materials is polyether ether ketone (PEEK). It is an organic thermoplastic material with high mechanical and chemical efficiency. This material has been much used by dental technicians. This machinable material is highly biocompatible and has low modulus of elasticity

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4 MPa. Being elastic as bone it provides a cushion effect and reduction of stress transfer to the abutments. (Papathanasiou et al. 2020).

Another emerging ceramic material is the recent advancement of Lithium disilicate which was introduced to the market at 2021 through SIRONA company. It was named as "CEREC-Tessera". The newly introduced ceramic possesses unique properties such as rapid rate of firing 4.5 to 12 min at 760 °C, flexural strength 700 MPa. The fast firing time is contributed to the two part crystal composition of lithium disilicate, (Lithium disilicate + Virgilite) embedded in a glassy zirconia matrix. This provides a fast, time saving processing option in addition to markedly high strength properties (Hashem 2023).

These advancements in materials have replaced the gold standard that has been used for decades which was the porcelain fused to metal ceramic restorations that combine both good aesthetics as well as high strength properties.

Therefore, the aim of the following study was to assess and compare the use of three different materials for the fabrication of fixed free dental prosthesis using finite element analysis. Total deformation, Von Mises stress maximum amount and sites on the bone and the fixed dental prosthesis body were compared. Null hypothesis is that there is no difference in the stresses transmitted to bone when using PEKK, PFM or Tessera for fabrication of fixed free dental prosthesis.

Methods

Finite element model has been made after scanning a fixed free fixed dental prosthesis. Dental prosthesis geometry had been obtained by the use of three D scanner (Roland Modela-model MDX-15-Roland DG Co. Hamamatsu, Japan) with graphics software (Roland's Dr. PICZA 3™), using Roland active piezoelectric sensor. This scanner form data file with cloud of points coordinates.

Another program was needed (Rhino 3.0-McNeel inc., Seattle, WA, USA) to adjust new formed surface by the points. At the end, the prosthesis out surface had been closed then filled to form volume representing solid structure. This structure geometry had been exported to finite element software in the form of STEP format. In addition, this was done with bone and reduced abutments. Cement with 40 microns thickness was formed by scaling bone and teeth before the use of Boolean operations (like subtract or cut), keeping only the cement (Al Qahtani and El-Anwar 2018; Al Qahtani et al. 2018).

Assumption for homogeneous materials were stated, also being isotropic and with linear elasticity, their properties are in a list in Table 1. The components (cement, base and bridge) had been exported as STEP files then inserted in finite element package ANSYS workbench version 16 (ANSYS Inc., Canonsburg, USA) for assembling and analysing.

Parabolic tetrahedral element had been used to mesh the model. Mesh density of components is listed in Table 2. The model of the prosthesis on ANSYS is shown in Fig. 1.

Modelling and element analysis (linear static) have been done on workstation hp z820, by dual Intel Xeon e5-2660, 2.2 GHz processor and 64 giga ram. 3 runs have been done with 3 fixed prosthesis materials. Compressing loading of 100 neutons had been exerted over

Table 1 Properties inserted into the finite element software

The materials	Young's Modulus	Poisson's Ratio
Base	18,600	0.31
Cement	12,600	0.25
PFM	149,450	0.34
Tessera	103,000	0.229
PEKK	5100	0.4

Table 2 Mesh density

	Nodes	Elements
Base	49,780	33,086
Cement	17,285	6213
Fixed prosthesis	599,206	416,125
Total	666,271	455,424

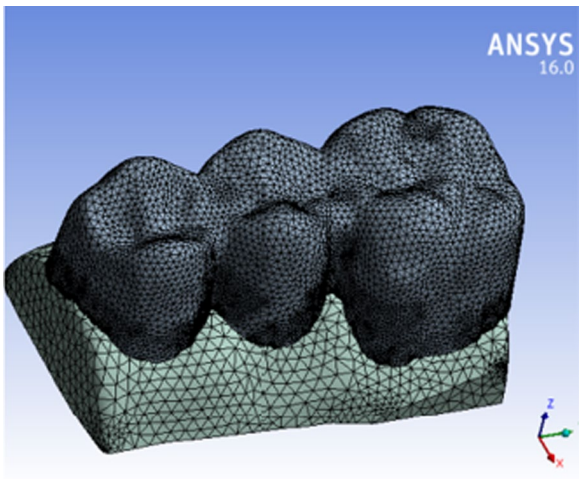

Fig. 1 The model of the prosthesis on ANSYS

central fossa of pontic, in the mean while models base had been considered as boundary condition.

Results

The fixed prosthesis material did not influence the location of total deformation, but the values had been changed. There was deformation in the pontic towards the ridge and this was the site of maximum deformation in the fixed prosthesis. But the maximum deformation regarding the cement and the reduced abutment were at the sites near the pontic as shown in Fig. 2

Sites and amount of maximum von Mises stress with the 3 materials showed that the most vulnerable site is the retainer margins near the pontic. Here, maximum von Mises stresses are exerted over bone and cement (Fig. 3), the pontic connector with the retainers received high amounts of stresses because of flexing due to loading.

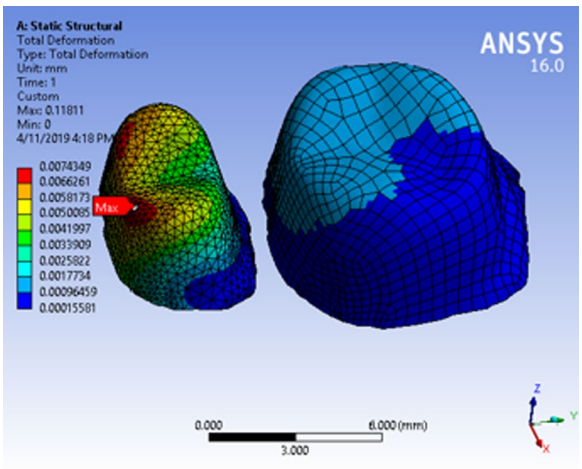

Fig. 2 The maximum deformation regarding the cement and the reduced abutment were at the sites near the pontic

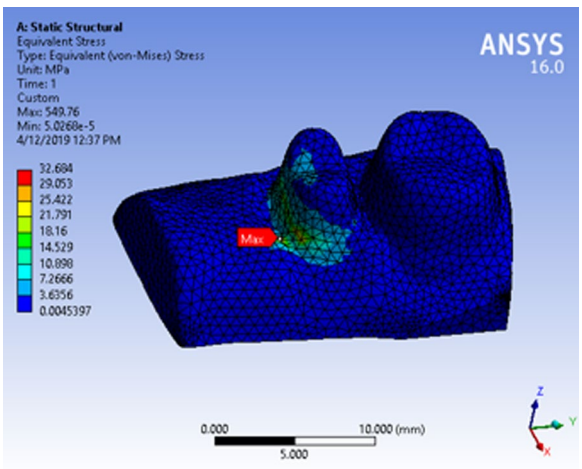

Fig. 3 Maximum von Mises stresses are exerted over bone and cement

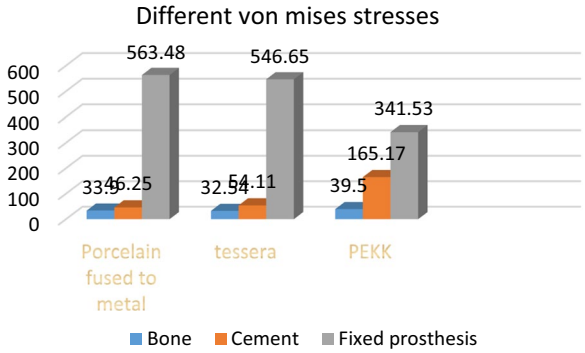

Fig. 4 Different von misses stresses

When data of the three cases was compared (Figs. 4 and 5), it was found that with the Tessera fixed prosthesis there were 4% von Mises stresses on bone lower than porcelain fused to metal fixed prosthesis. However, regarding the cement there were 17% von Mises stresses on bone higher than the porcelain fused to metal fixed prosthesis. PEKK fixed prosthesis showed the most amounts of stresses and deformations.

Discussion

The increased aesthetic need has led to much increased use of metal-free restorative materials. The most recent of these materials are CAD/CAM fabricated ceramics. These materials and techniques enabled more precise, easy, fast and simple fabrication of the final restorations with more comfort to both patient and prosthodontist in addition to time saving. In what is meant to be a fully digital era (Soares et al. 2021).

The use of fixed dental prosthesis to restore missing teeth with wide variations of designs is increasingly and widely applied in dental clinics all over the world. Cantilever bridge design the fixed free dental bridge has proved to be a viable alternative solution for these problems. When several teeth are missing or bone is deficient, the option is not necessarily dental implants, it could be cantilever dental bridge (Yaagoubi et al. 2021).

Kharakh et al. (2020) concluded from their study that it is problematic and complicated to select the proper material for the prosthetic restoration because strength values should exceed 950 MPa to withstand stresses.

Fixed free fixed dental prostheses could be now a predictable mode of treatment, that was stated by Roccuzzo et al. (2020) after detailed radiographic as well as clinical assessment. Porcelain fused to metal were developed in an attempt to improve both

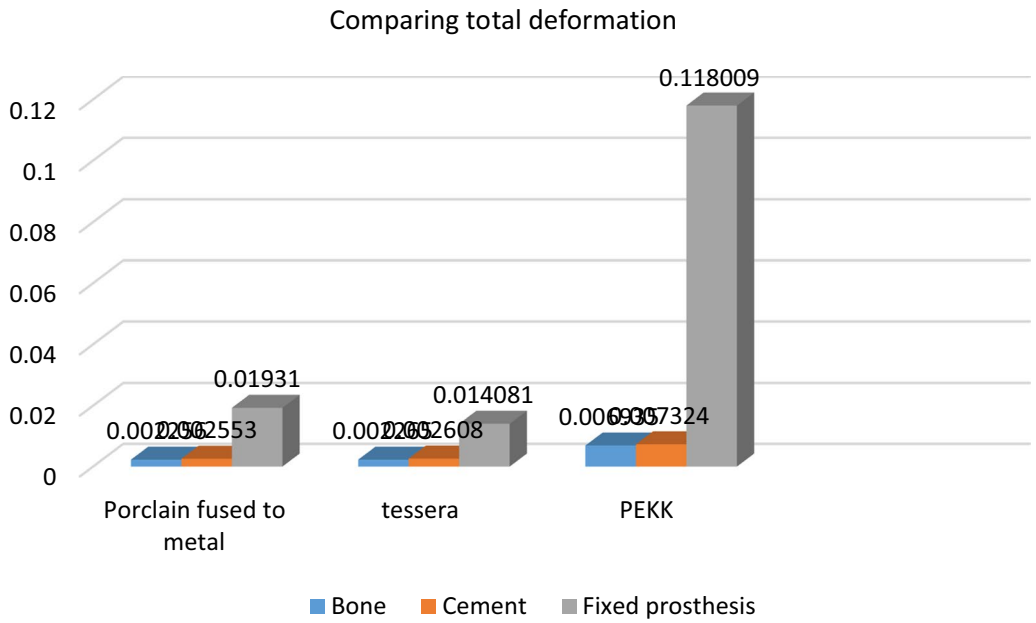

Fig. 5 Comparing data of three cases

aesthetics as well as longevity of fixed dental prosthesis. However, some draw backs of metal ceramic prostheses regarding aesthetics, biocompatibility and massive tooth preparation emerged which led to the evolution of all ceramic materials.

Clinical in-vivo studies consume time and need plenty of money and several clinical and technical steps. In addition, the standardization process for research work is difficult at different times. This fact made researchers introduce new methods to simplify their research work. The introduced methods could replace clinical research and give similar results. Finite element analysis (FEA) is a tool or software used for the validation of the mechanical behaviour of materials and experiments. Its popularity increased as it is able to mimic complex structures into models and translate important information about stress and strain distributions in prosthetic components and surrounding tissue. Moreover, new designs could be suggested and various materials could be simulated in terms of properties and criteria. It offers simplicity and trueness in research work. In this study, FEA was applied to determine the total deformation, Von Mises stress maximum amounts and sites on the bone, and the fixed dental prosthesis body for the tested materials (Shash et al. 2023).

PEKK has been widely used in dental applications as orthopedics as well as dental implants, abutments and interim restorations. It has been popular among dentist and technicians owing to its high modulus of elasticity. However, there are different research debates concerning its strength properties (Qin et al. 2021).

Resembling chameleon PEKON (commonly known as PEKK) aesthetically adapts to the surrounding structures. It offers high stiffness, ease of processing. Moreover, PEKK possesses ideal viscosity, large working temperature range as well as declined shrinking rates upon cooling down. Studies have proved high values of accuracy reached with use of Pekkton. In addition to its reinforcement with fibres (Yousief, et al. 2019).

However, in our study the PEKK fixed prosthesis showed the most amounts of stresses and deformations. This is attributed to its low modulus of elasticity and high stiffness allowing more stress transfer to the abutment teeth and underlying structures. This was in accordance with other researches and studies. Where, according to Demerci et al. (2022), metal-free materials preferred in three-unit FDPs have different mechanical behaviours. A ductile fracture pattern was observed in high-performance polymers (PEEK, PEKK, and FRC) due to their elastic structures. Moreover, according to Lou et al. (2023), the stiffness of PEEK may not be sufficient to withstand load-bearing stresses and there is a higher risk of fracture.

Campaner et al. (2021) reported that PEEK is considered a suitable material for restorations in load-bearing occlusal areas. However, due to the its low modulus of elasticity, PEEK can be only enough to be

a temporary material not efficient to construct final restorations.

However, other researches had an opposing opinion and different results. It was reported that PEKK has tensile properties comparable to those of enamel and dentin that`s why it has been used as a successful alternative for fixed restorations. (Knaus et al. 2020).

Qin et al. (2021) reported the use of PEEK as an implant material, CAD/CAM material as well as abutment material owing to excellent mechanical properties.

Besides, load-bearing test results of PEEK (995.52 78.1 N) indicated that it could be used as a substitute to the resin-based FPD material, as shown by Cekic-Nagas et al. (2018).

High survival and success rates were reported for PFM restorations with a survival rate of 95–97% for a period of 7 years. And after 20 years a cumulative success rate reached about 65% (Yousief, et al. 2019).

Cerec Tessera CAD/CAM material has been newly introduced to the market at 2021. It delivers superior aesthetics through a fast processing path thus saving patient`s as well operator`s valuable time. It possesses high-defining strength reaching 32%. This material represented Dentsply Sirona`s new advancement of lithium disilicate CAD/CAM blocks (Tessera, Dentsply Sirona) to the prosthodontic field. This ceramic is characterized primarily by the fact that it can be fired exceptionally quickly. The glaze firing takes just four and a half minutes, this fast firing time was attributed to the new composition of the ceramic composed of disilicate of lithium and virgilite, a lithium aluminium silicate. It has several indications such (as the anterior and posterior region for crown, inlay, onlay, and veneer (Marchesi et al. 2021).

In our study results showed that with the Tessera fixed free fixed prosthesis there were 4% von Mises stresses on bone lower than porcelain fused to metal fixed prosthesis. That was simply explained by the high biaxial strength of Tessera reaching about 700 MPa which led to decreased amount of transferred stresses to the underlying structures.

Results of our study showed that the site where the margins of the retainers rest on the tooth structure is very important especially near the pontic. Studies by Campaner et al. (2021) showed that the rigidity of the abutment material strongly affects the distribution of the masticatory loading stresses transmitted to underlying structures.

The fixed free dental prosthesis could be alternatively used to prevent surgical procedures thus saving time, cost and surgical morbidity. However the biomechanics of cantilevers is debatable so far, since they are subjected to more complicated stresses than other prostheses designs. Although their performance is still questionable when used under defined criteria, they can have predictable results and successful end. Thus, to reach a successful design the clinical criteria that affect stress dissipation should be well-known. Such knowledge can decrease mechanical failures and improve the longevity of the fixed free designed prostheses (Amine et al. 2020).

Conclusions

Pure PEKK is not recommended as a fixed prosthesis material with the free pontic design.

Fixed prosthesis materials with low stiffness can aid in transferring less loading amounts to the underlying structures.

The site where the margins of the retainers rest on the tooth structure is very important especially near the pontic.

Abbreviation

PEKK Polyetherketoneketone

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Author contributions

R.M analysed and interpreted the data in addition to doing practical work. MM performed the plagiarism and was a major contributor in writing the manuscript. G.E made statistical analysis. Y.A revised the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

All data and material are available upon reasonable request.

Declarations

Ethics approval and consent to participate

No ethical approval needed as it is an in-vitro study

Consent for publication

Not applicable

Competing interests

No competing interests.

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