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ANALYSIS OF STRESS DISTRIBUTION AND FRACTURE RESISTANCE OF ZIRCONIA AND *POLYETHERETHERKETONE* POSTERIOR FIXED PARTIAL DENTURE BY DIFFERENT CONNECTOR DIMENSIONS USING *FINITE ELEMENT ANALYSIS*

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Abstract

Background*: Patients who have lost one or more teeth will be rehabilitated by fixed partial dentures (FPD). The last decade shows interest in all-ceramic materials and polyetheretherketone (PEEK) as alternatives to metal FPD. The success of any FPD is strongly influenced by biomechanical factors, therefore, it is important to evaluate the stresses in the structure and those transferred to the surrounding tissue, especially the connector area. The most popular technique for examining the effect of dental restoration materials on the stress distribution in fixed partial dentures is finite element analysis.* ***Purpose****: The study aimed to analyze the stress distribution and fracture resistance of zirconia and PEEK posterior FPD at different connector dimensions using finite element analysis.* ***Material and Methods****: Six 3D models of the FPD framework replaced the second premolar, first molar and second constructed on a computer (AutoCAD 2016 software) for simulation. Frameworks were constructed by connector dimensions of 9 mm^2, 12.25 mm^2 and 16 mm^2, continue applied 600 N load axially on the centric fossa of pontic to analyze stress distribution and fracture resistance between zirconia and PEEK framework material.* ***Results:*** *Decrease in the value of stress concentration in connector dimension 9 mm^2; 12,25 mm^2 dan 16 mm^2 zirconia (260.54 MPa, 209.53 MPa dan 149.38 MPa) to PEEK (247.14 MPa, 200.26 MPa and 144.49 MPa), and there is a difference in the maximum equivalent (von mises) stress of FPD posterior with connector dimension 9 mm^2, 12.25 mm^2 and 16 mm^2 of zirconia (260.54 MPa, 209.53 MPa and 149.38 MPa) to PEEK (247.14 MPa, 200.26 MPa and 144.49 MPa), meanwhile, the difference of maximum equivalent (elastic) strain [zirconia (0.0013, 0.0010 and 0.0007) and PEEK (0.0645, 0.0506 and 0.0373)] and total deformation [zirconia (0.0032 mm, 0.0031 mm and 0.0027 mm) and PEEK (0.1889 mm, 0.1624 mm and 0.1443 mm)] of PEEK posterior FPD were higher compare to zirconia.* ***Conclusion****: PEEK posterior FPD had higher fracture resistance compared to zirconia because it could reduce the stress concentration in the connector area.*

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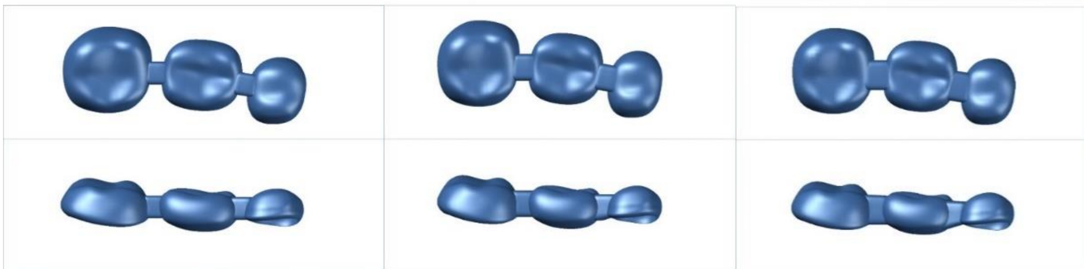
Keywords: *Connector Dimension, Fracture Resistance, Polyetheretherketone, Stress Distribution, Zirconia.*

INTRODUCTION

Tooth loss can be replaced with dentures, and if not replaced, will cause functional and aesthetic problems for the patient.[1] Generally, patients who have lost one or more teeth will be rehabilitated by fixed partial dentures (FPD) because they are more comfortable and non-removable. Commonly materials used as FPD are full metal, metal-ceramic, metal-resin, or metal-free combinations.[2] The most popular all-ceramic material used for the fabrication of FPD is zirconia.[3] The last decade shows interest in Polyetheretherketone (PEEK) as an alternative to metal. PEEK as a retainer material provides a shock absorbent effect during mastication and has high resistance to abrasion and caries.[4,5] The design of the FPD is very important to reduce the stress on the abutment teeth and surrounding bone tissue, especially the connectors.[6,7] The success of FPD is strongly influenced by biomechanical factors, therefore, it is important to evaluate the stresses in the structure and those transferred to the surrounding tissue.[8] The most popular technique for examining the effect of dental restoration materials on the stress distribution in dentures is finite element analysis. Although there have been some studies on the stress distribution and fracture resistance of PEEK materials, there have been no studies analyzing the stress distribution and fracture resistance framework of FPD posterior zirconia and PEEK at different connector dimensions.

MATERIAL AND METHODS

The external shape of the solid model is obtained by scanning the typodont models of teeth 35 and 37 that preparation with the angle of 6º, chamfer-shaped finishing line and rounded, the model is then scanned.[9] Six models of 3D FPD framework that replace the second premolar, first molar and second molar were constructed on the computer (AutoCAD 2016 software) for simulation. The frameworks are constructed with different connector dimensions as follows: 9 mm^2, 12.25 mm^2 and 16 mm^2 (figure 1) to compare stress distribution and fracture resistance between FPD framework zirconia and PEEK materials on different connector dimensions. All material properties used are mechanical properties of the material based on previous literature and research (table 1).



(a) (b) (c)

Figure 1: Three 3D models with various connector dimension (a) 9 mm^2 (b) 12,25 mm^2 (c) 16 mm^2

Tabel 1: Mechanical properties used in FEA model

Material	Modulus elastisitas (MPa)	*Poisson's Ratio*
Zirconia	210.000	0.27
PEEK	4000	0.30

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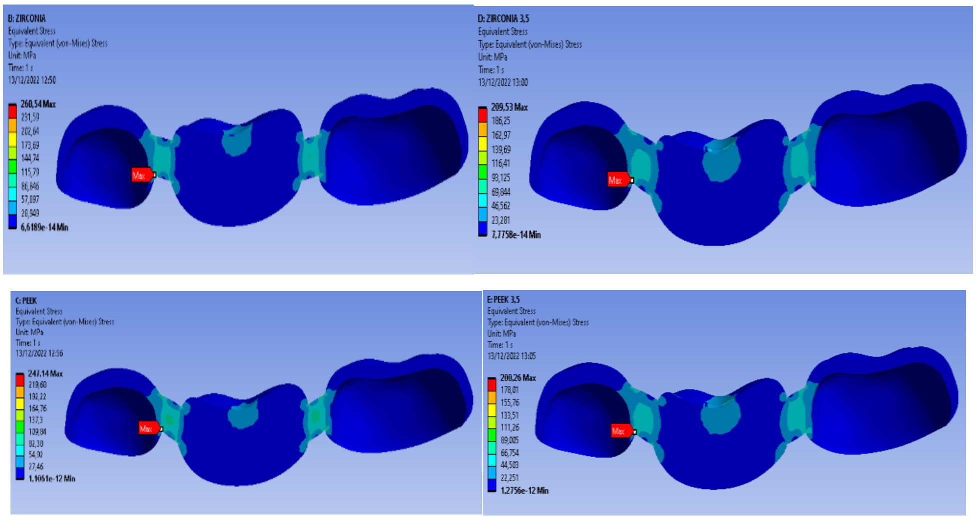
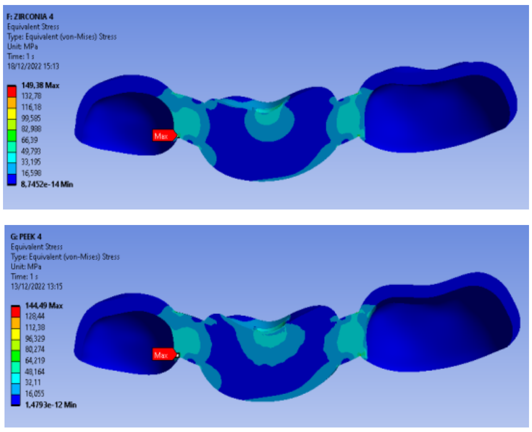
Determination boundary conditions which are the surface of the intaglio retainer of tooth 35 and 37. The load is applied to the pontic at the central fossa of the first molars in the 3D model with a load of 600 N to represent the maximum bite force applied in a longitudinal axis so that the simulation performed is close to the real state in the mouth.[10] Equivalent (Von Mises) stress are used to analyze stress distribution and ANSYS 17.2 software calculates it as the square average of normal voltages at the base, middle or above the element. Stress produced is expressed in megapascals (MPa) and deformation is expressed in millimeters (mm).

RESULTS

The results of the analysis are obtained by the value and spread of von Mises color plots to obtain total deformation, equivalent (Von Mises) stress and equivalent (elastic) strain as parameters that indicate stress distribution and fracture resistance. The color contour plots that appear are red, orange, yellow, green and blue. Color determines the level of stress/strain that occurs, where red is the maximum point while blue is the minimum point. The following illustrates the difference of stress distribution (equivalent stress) (figure 2), equivalent strain (figure 3), and total deformation (figure 4) of zirconia to PEEK posterior FPD at various connector dimensions (9mm^2; 12.25mm^2 and 16mm^2.



(a) (b)



(c)

Figure 2: Difference of equivalent (von mises) stress in zirconia-PEEK posterior FPD at various connector dimensions (a) 9 mm^2, (b) 12.25 mm^2 and (c) 16 mm^2

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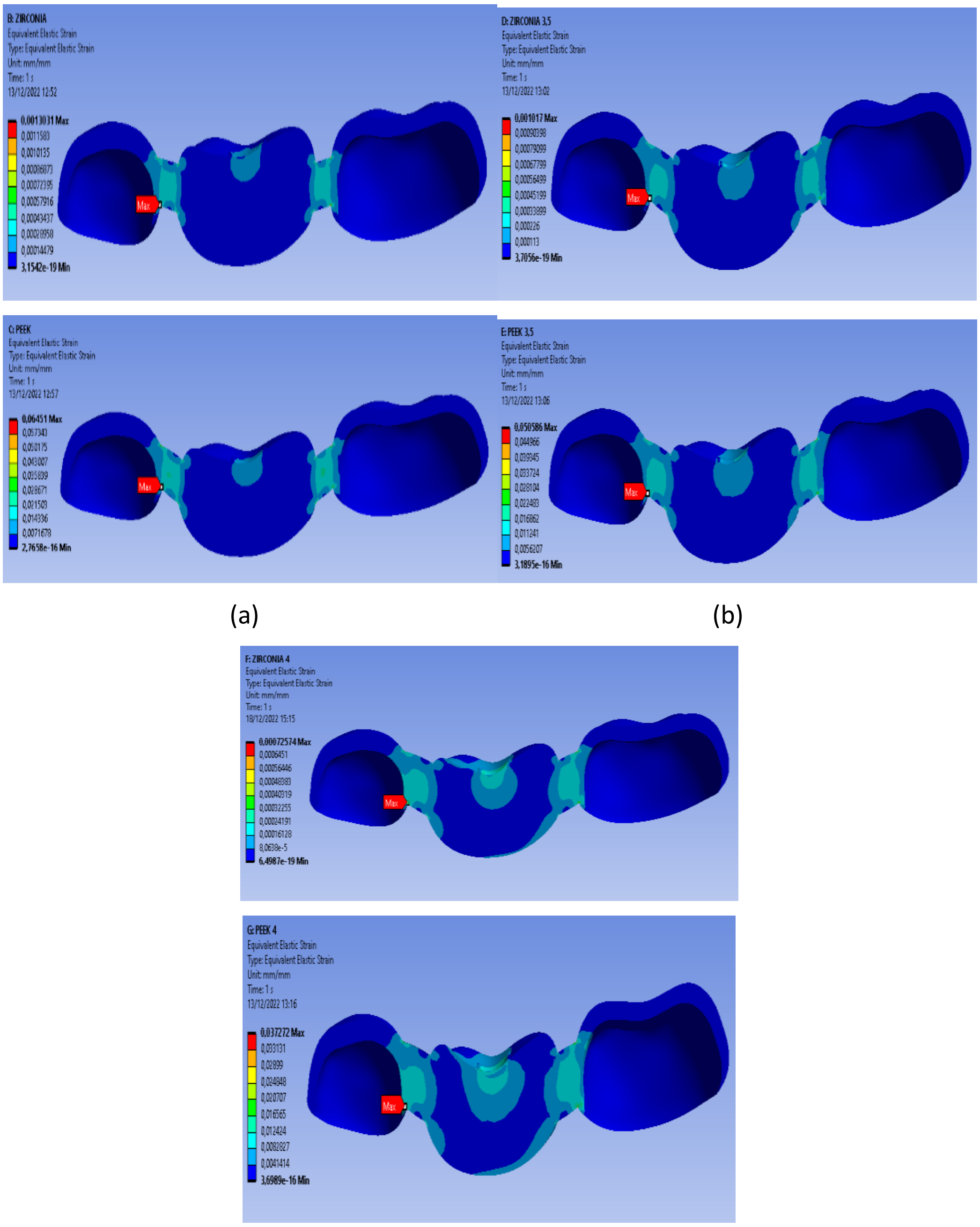

Figure 3: Difference of equivalent (elastic) strain in zirconia-PEEK posterior FPD at various connector dimensions (a) 9 mm², (b) 12.25 mm² and (c) 16 mm²

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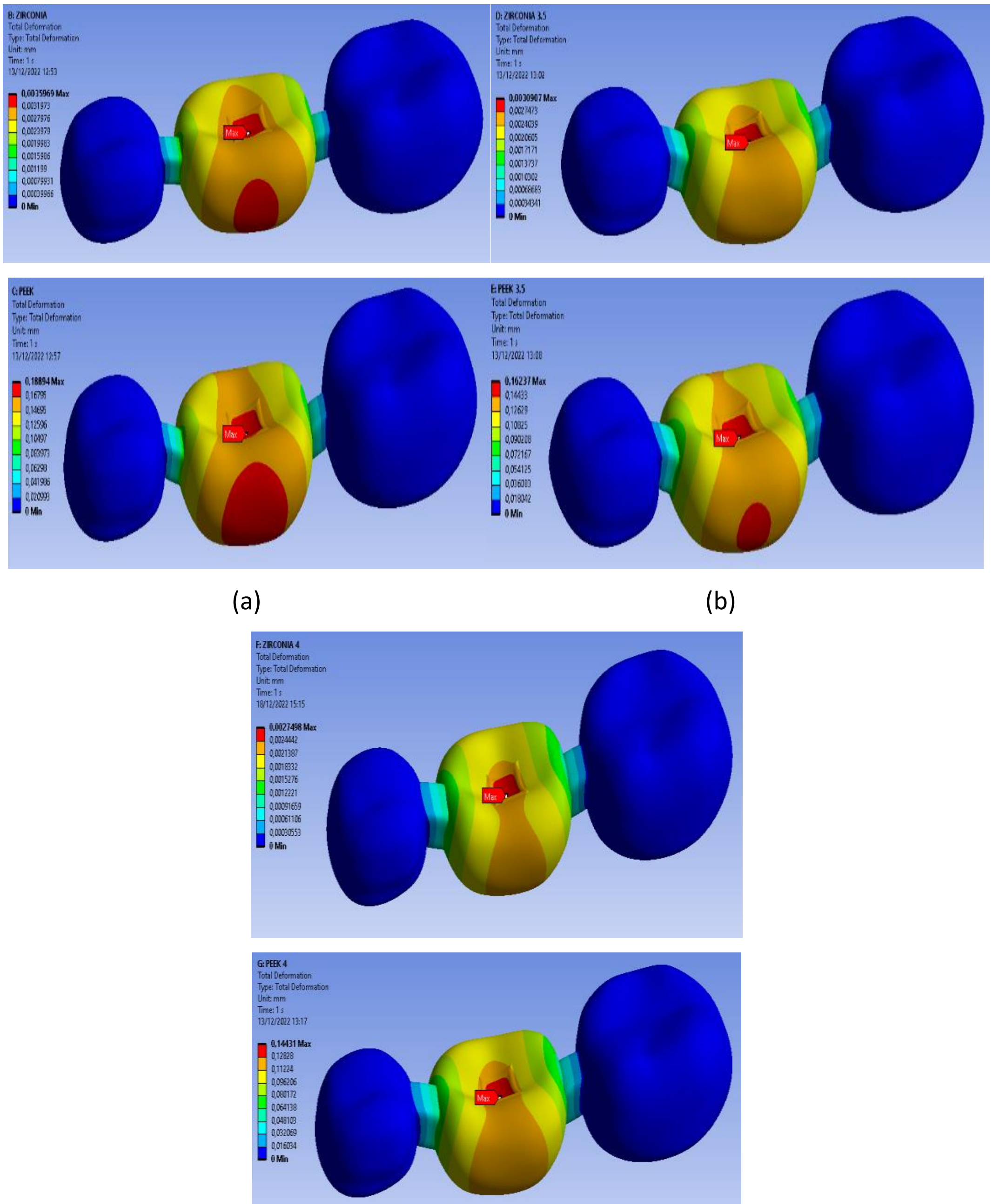

Figure 4: Difference of total deformation in zirconia-PEEK posterior FPD at various connector dimensions (a) 9 mm^2, (b) 12.25 mm^2 and (c) 16 mm^2

The following table illustrates the differences in fracture resistance between FPD zirconia to PEEK on connector dimensions 9 mm^2 (table 2), 12.25 mm^2 (table 3) and 16 mm^2 (table 4).

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Table 2: The difference in fracture resistance of zirconia to PEEK posterior FPD at 9 mm^2 connector dimensions

Material	Fracture resistance of zirconia to PEEK posterior FPD at 9 mm^2 connector dimensions		
	Total deformation (mm)	Maximum equivalent (Von Mises) stress (MPa)	Maximum equivalent (elastic) strain
Zirconia	0,0032	260,54	0,0013
PEEK	0,1889	247,14	0,0645

Table 3: The difference in fracture resistance of zirconia to PEEK posterior FPD at 12,25 mm^2 connector dimensions

Material	Fracture resistance of zirconia to PEEK posterior FPD at 12,25 mm^2 connector dimensions		
	Total deformation (mm)	Maximum equivalent (Von Mises) stress (MPa)	Maximum equivalent (elastic) strain
Zirconia	0,0031	209,53	0,0010
PEEK	0,1624	200,26	0,0506

Table 2: The difference in fracture resistance of zirconia to PEEK posterior FPD at 16 mm^2 connector dimensions

Material	Fracture resistance of zirconia to PEEK posterior FPD at 16 mm^2 connector dimensions		
	Total deformation (mm)	Maximum equivalent (Von Mises) stress (MPa)	Maximum equivalent (elastic) strain
Zirconia	0,0027	149,38	0,0007
PEEK	0,1443	144,49	0,0373

DISCUSSION

The fracture is one of the failures of FPD restoration. The following factors must be present simultaneously to cause a fracture, namely the presence of (1) a stress concentration that can become a crack and the presence of (2) high stress to cause microscopic plastic deformation at the end of the stress concentration.[11] Deformation, stress and strain that occur in a material after applying a biomechanical load will have an influence on the occurrence of fractures in the material which means it will also affect the fracture resistance of a material which can be observed by FEA simulation. This method can be done to see the fracture resistance and stress distribution of a restoration design.

At 9 mm^2 connector dimensions, the stress concentration occurs connector area, leading to the pontic. The stress distribution pattern shows almost the same results, but in the PEEK posterior FPD, the stress distribution is slightly more even compared to the zirconia posterior FPD which shows a higher concentration in the connector to the pontic in the gingival embrasure. There is also a difference in total deformation, maximum equivalent (Von Mises) stress and equivalent (elastic) strain between zirconia and PEEK posterior FPD. The total deformation values of the posterior FPD zirconia is 0.0036 mm and PEEK is 0.1889 mm, indicate a marked difference in total deformation. The total deformation of the PEEK posterior FPD is 52 times greater than zirconia at 9 mm^2 connector dimensions. The maximum difference in equivalent (Von Mises) stress between zirconia and PEEK posterior FPD is 13.4 MPa with a maximum value of equivalent (Von Mises) stress greater analyzed in zirconia posterior FPD (260.54 MPa) than PEEK (247.14 MPa). In this study, there was also a maximum difference in equivalent (elastic) strain between the two materials. The maximum value of the equivalent (elastic) strain of the zirconia posterior FPD is 0.0013 mm and PEEK 0.0645 mm, there is a noticeable difference in the maximum equivalent (elastic) strain. The maximum equivalent (elastic) strain of PEEK posterior FPD is 50 times greater than zirconia with connector dimensions of 9 mm^2.

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At connector dimensions of 12.25 mm^2, the stress distribution is most visible in the connector area to the pontic. The stress distribution pattern shows almost the same results between zirconia and PEEK, but in PEEK posterior FPD there is a stress concentration in the connector region of the gingival embrasure surface, but in PEEK posterior FPD, the stress is more evenly distributed to the retainer compared to zirconia. There is also a difference in total deformation, maximum equivalent (Von Mises) stress and equivalent (elastic) strain between zirconia and PEEK posterior FPD. The total deformation value of the zirconia posterior FPD is 0.0031 mm and PEEK is 0.1624 mm, there is a noticeable difference in total deformation. The total deformation of PEEK posterior FPD is 52 times greater than zirconia at connector dimensions of 12.25 mm2. The maximum difference in equivalent (Von Mises) stress between the zirconia and PEEK posterior FPD is 9.27 MPa with a greater maximum value of equivalent (Von Mises) stress analyzed in the zirconia posterior FPD (209.53 MPa) to PEEK (200.26 MPa). In this study, there was also a maximum difference in equivalent (elastic) strain between the two materials. The maximum value of the equivalent (elastic) strain of the zirconia posterior FPD is 0.0010 mm and PEEK is 0.0506 mm, there is a noticeable difference in the maximum equivalent (elastic) strain. The maximum equivalent (elastic) strain of the PEEK posterior FPD is 51 times greater than zirconia with connector dimensions of 12.25 mm^2.

At the connector dimension of 16 mm^2, the stress distribution is mostly seen in the connector area leading to the pontic. The stress distribution pattern shows almost similar results, namely the stress concentration in the gingival embrasure surface at the connector region, but in the PEEK posterior FPD, the stress is spread more evenly towards the connector region to the retainer when compared to the zirconia. There is also a difference in total deformation, maximum equivalent (Von Mises) stress and equivalent (elastic) strain between zirconia and PEEK posterior FPD. The total deformation value of the zirconia posterior FPD is 0.0027 mm and PEEK is 0.1443 mm, there is a noticeable difference in total deformation. The total deformation of the PEEK posterior FPD is 53 times greater than zirconia at connector dimensions of 16 mm^2. The maximum difference in equivalent (Von Mises) stress between zirconia and PEEK posterior FPD is 4.89 MPa with a maximum value of equivalent (Von Mises) stress greater analyzed in zirconia posterior FPD (149.38 MPa) than PEEK (144.49 MPa). In this study, there was also a maximum difference in equivalent (elastic) strain between the two materials. The maximum value of the equivalent (elastic) strain of zirconia posterior FPD is 0.0007 mm and PEEK is 0.0373 mm, there is a noticeable difference in the maximum equivalent (elastic) strain. The maximum equivalent (elastic) strain of the PEEK posterior FPD is 53 times greater than zirconia with connector dimensions of 16 mm^2.

According to Attria (2018) and Lakshmi et al (2015), the stress distribution in FPD is very dependent on the properties of the material and geometric configuration. The modulus of elasticity of the material is an important parameter for the manufacture of FPD. Ideally, the modulus of elasticity of the material used should be close to the modulus of elasticity of the teeth, so that an even stress distribution can be obtained. Framework design and material properties used in the fabrication of FPD play an important role in stress distribution.[12-15] According to Bakit et al (2017), PEEK material has high flexibility, so the restoration of PEEK material can distribute the received stress more evenly.[4] According to Biyao (2022) and Rodriguez et al (2021), the modulus of elasticity also plays an important role in the stress distribution, PEEK has a lower modulus of elasticity compared to zirconia, it causes a more even stress distribution found in PEEK FPD compared to zirconia.[16,17] According to Kozua et al (2011), fracture resistance increases with an increase in connector dimensions, this statement is based by research conducted by Lakshmi et al (2016).[13,18]

From the results obtained, it can be analyzed that the dimensions connector and the material used greatly affect the stress distribution in the posterior FPD. In the analysis of the difference in stress distribution in the zirconia to PEEK posterior FPD based on different connector dimensions (9 mm^2;

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12.25 mm^2 and 16 mm^2), it can be seen that there is a difference in the stress distribution that occurs at the connector area between zirconia and PEEK. Stress is distributed more widely from the direction of the connector to the retainer area as increasing connector dimensions of the posterior FPD.[19] Modulus elasticity, load force and the size of the connector dimensions influence the simulation results, namely the total deformation value, equivalent (Von Mises) stress and equivalent (elastic) strain as criteria to see fracture resistance and stress distribution experienced by a design. Dimensions connector will determine the success of FPD. However, dimension connectors that are too large will hinder good plaque control which can cause periodontal problems and interfere with the aesthetics of restoration.[20] Although finite element analysis is a good and easy research method, it is necessary to conduct further tests on the posterior FPD framework with various connector dimensions with experimental research designs to get more accurate results.

CONCLUSION

PEEK posterior FPD has higher fracture resistance compared to zirconia because it can reduce the stress concentration in the connector area. PEEK posterior FPD has a shock absorbent effect indicated by the equivalent (elastic) strain and total deformation value fifty times greater than zirconia, at connector dimensions of 9 mm^2 zirconia and PEEK posterior FPD have been able to withstand maximum masticatory loads without fracture so that the fabrication of zirconia and PEEK posterior FPD with dimensions of 9 mm^2 can increase aesthetic needs without reducing the fracture resistance of FPD.

Suggestion

Further finite element analysis needs to be carried out to evaluate the stress distribution from the posterior FPD to the abutment at different connector dimensions that have not been seen in this study.

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