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ANALYSIS OF STRESS DISTRIBUTION IN SINGLE POSTERIOR ZIRCONIA, LITHIUM DISILICATE AND POLYETHERETHERKETONE (PEEK) CROWN RESTORATION WITH FINISH LINE DESIGN USING FINITE ELEMENT ANALYSIS

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Abstract

Background: *All-ceramic crown restorations frequently used in prosthodontics as metal-free restoration because of their esthetics, biocompatibility, and inert properties, however fracture remains a complication. Stress distribution in all-ceramic crowns during mastication reported to be higher on cervical area than occlusal surface according to finite element analysis (FEA). Cervical area are vulnerable and may induce cracks from the occlusal surface to cervical. Shoulder and chamfer finish line design were recommended design for crown restoration and had influence in stress distribution. Mechanical properties of restoration material such as modulus elasticity is an important factor that must be considered. Besides all-ceramic material, polyetheretherketone (PEEK) material have widely been used on medical field. PEEK provides a shock absorbent effect, biocompatible with good esthetics which can be considered as an alternative restoration material.* ***Objectives:*** *This study aims to analyze zirconia, lithium disilicate and PEEK posterior crown restoration stress distribution with finish line design using FEA software (ANSYS v17.2; ANSYS Inc, Canonsburg, PA, USA)* ***Material and Method:*** *Six 3D mandibular first molar models of two type finish line designs; shoulder and chamfer were prepared using AutoCAD 2016 software and crown restoration 3D designed. FEA simulation then started with loading condition, simulating average human maximum bite force of 600 N axially to the occlusal surface at the center of the crown.* ***Result:*** *Stress on zirconia and lithium disilicate crowns was localized on occlusal loading area as well as internal restoration axial wall and cervical region within restoration. Contrastly for PEEK crown, stress got absorbed and disperse to the underlying abutment. The lowest von Mises stress values showed on zirconia crown with shoulder finish line design (20,301 MPa) compared to chamfer (22,264 MPa), and both lithium disilicate (14,039 MPa) and PEEK (0,444 MPa) crown with chamfer finish line design compared to shoulder lithium disilicate (16,496 MPa) and PEEK (0,473 MPa). These result suggest that on zirconia crown, it needs a wide margin area such as shoulder finish line design to minimize stress, meanwhile on lithium disilicate and PEEK crown, chamfer finish line design distribute stress evenly so that crown restoration survival can be expected to improve.*

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Vol: 60 | Issue: 11 | 2023

Conclusion: *PEEK crown prevent stress concentration on crown cervical area, implying PEEK can be use clinically as alternative restoration material.*

Keywords: *Crown Restoration, All-Ceramic, Peek, Stress Distribution, Finish Line Design, Finite Element Analysis.*

INTRODUCTION

Damage that occurs to the crown of the tooth is generally restored with a crown restoration. The choice of restoration in cases of tooth decay with crown restoration preferred because the durability rate of this restoration is 77.8% - 89.2% after 10 years of use.[1] one of the requirements for the success of a crown restoration is the principle of tooth preparation including biological, mechanical and aesthetic consideration. Tooth preparation design for crown restoration must follow mechanical principles by providing retention and resistance so that the restoration cannot be dislodged, distorted, or fractured during wear.[2, 3]

Mechanical resistance of the crown affected by the presence of superficial defects and internal space in the crown. Such defects can initiate cracks. This can be influenced by factors such as load size, stress distribution, inadequate tooth preparation, restoration thickness, and oral conditions. Inadequate tooth preparation such as finish line design is the main reason for the decreased resistance of crown restoration. Chamfer and shoulder finish line design were commonly used. To date, there is insufficient evidence to decide which finish line design provides better stress distribution in all ceramic crown restoration. Many studies have been done to evaluate the effect of finish line design on fracture load but the results inconclusive.[4-8]

In-vitro laboratory test of all ceramic crown is expensive and time-consuming, but finite element analysis (FEA) allows studies of stress distribution through model simulation, which can be used to examine the role of finish line design variation. FEA can represent a simplification of clinical scenario and has become a reliable test in dental biomechanics. Von Mises stress from FEA analysis was used to evaluate the yield/failure properties of dental materials. Visualization of von Mises stress described through a color code that represent the tension intensity scale with blue indicates the lowest stress, and red the highest. The color values for medium stress are intersolated from cyan, green and yellow.[5, 8-10]

Costa et al (2014) reported stress distribution during mastication in crown restoration compared with unrestored teeth, a large load was noted on cervical line of crown with FEA.[6] Rocha et al (2011) stated that finish line design proved susceptible to fracture under maximum stress with FEA. The fracture pattern of the crown during clinical use suggests origin of fracture to be at crown cervical area and intaglio surface.[11] D'Souza et al (2017) concluded that area with maximum load concentrated at crown cervical area when given maximum bite force with FEA.[12]

Larger finish line preparation area, such as shoulder design suggest to ensure a better pattern of stress distribution during mastication but research result on this subject are inconsistent.[13] Some studies recommend shoulder design and others suggest chamfer design for maximum resistance to fracture.[2,13-22] Rosentsiel et al (2016) suggest shoulder design for buccal finish line of metal-ceramic or all ceramic crown and chamfer design for metal crown or lingual finish line of metal-ceramic crown.[3] Shilingburg et al (2012) stated that chamfer design provide good support for all ceramic crown but not better than shoulder design.[23]

Another requirement for successful crown is material selection that related to crown fracture resistance, has major influence on maximum stress of crown. All ceramic crown are currently consider gold standard but fractures remain a complication.[4,24] Goodacre et al (2003) reported clinical fracture

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Vol: 60 | Issue: 11 | 2023

rates of different ceramic crown, with 21% for molars, 7% for premolars, and 3% for anterior teeth.[25] One of the main problems of all ceramic crown are the possibility of fracture under occlusal and lateral loads.[5,18] Non-metal crown made from thermoplastic polymers; polyetheretherketone (PEEK) are a new material and have been introduced in dentistry, characterized by good biocompatibility, wear resistance, chemical stability, lightweight and good mechanical properties making it an alternative material for crown restoration. PEEK modulus of elasticity is 4-6 GPa close to bone, allowing it to act as shock absorber thereby reducing forces that transmitted to restoration. Advantages of PEEK are elimination of allergic reaction, good polishing properties, and low plaque adhesion.[1, 26]

This study analyze and compare stress distribution of shoulder and chamfer finish line design on single posterior crown made of zirconia, lithium disilicate and PEEK using FEA.

MATERIAL AND METHOD

Process of model construction and FEA simulation tests was carried out at Mechanical Engineering Computational and Experimental System Research Center J17 Floor 3 – Universitas Sumatera Utara, using ANSYS v17.2 software program (ANSYS Inc, Canonsburg, PA, USA) and AutoCAD 2016. The FEA study was conducted in two phases, namely the design phase of the 3D mandibular first molar model and 3D crown restoration with AutoCAD 2016 and the simulation and data analysis phase with ANSYS v17.2.

Fabrication of two 3D mandibular first molar abutment virtual models that had been prepared with shoulder and chamfer finish line design accompanied by 3D crown restorations using AutoCAD 2016 software (Figure 1). The two models were then duplicated to three models each to obtain six models that would use three different restorative materials, namely zirconia, lithium disilicate and PEEK. Guidelines for preparing abutment teeth using guidelines for all-ceramic crown restoration according to Rosentsiel; reduction 1.5 mm buccolingual, 1.5 mm occlusal, 1.5 mm mesial distal, 6° convergence angle and rounded corner (Figure 2). The 3D mandibular first molar crown restoration design uses the average human tooth size, namely crown diameter at the cervical base of 9 mm, 10.5 mm buccolingual, 7.5 mm high, and 11 mm occlusal diameter (Figure 3).

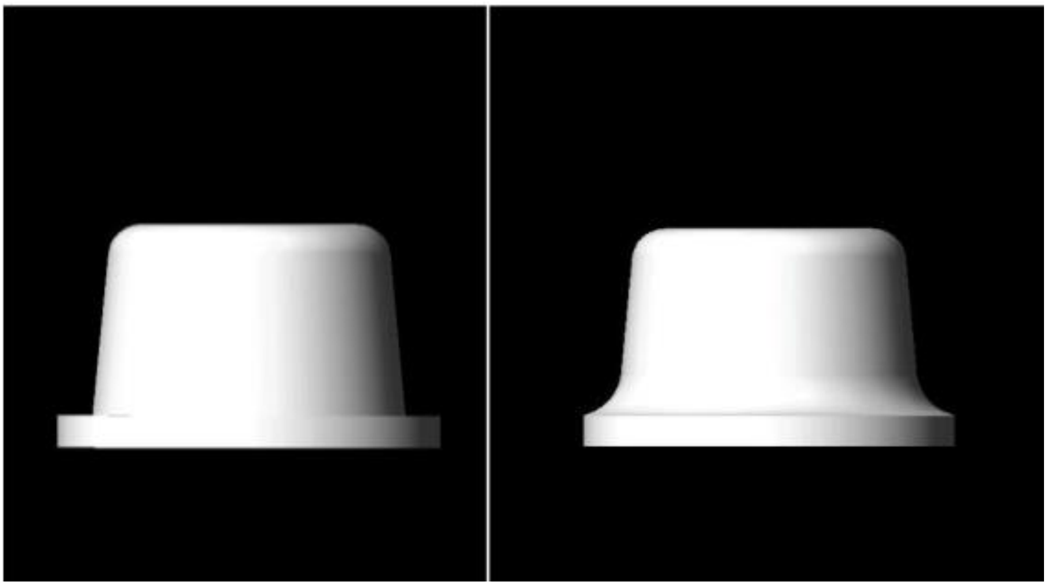

Figure 1: 3D Model; shoulder (left) chamfer (right)

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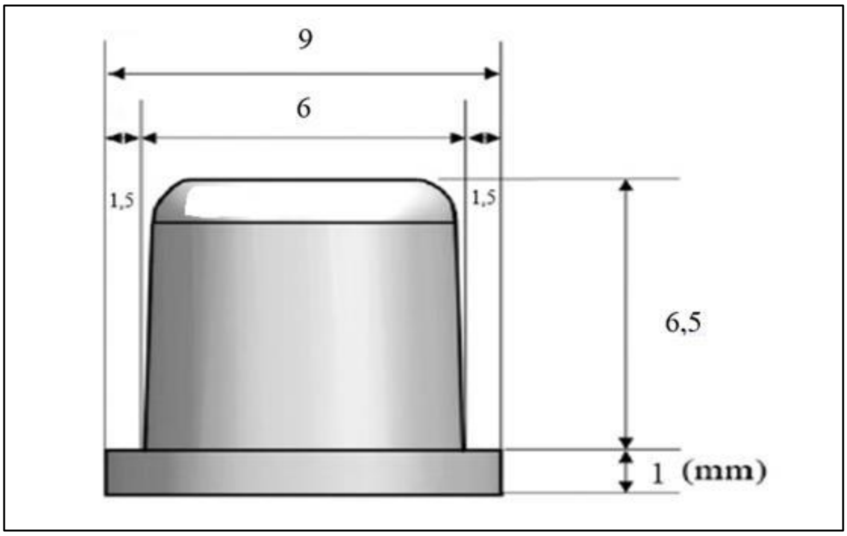

Figure 2: Tooth Preparation Design

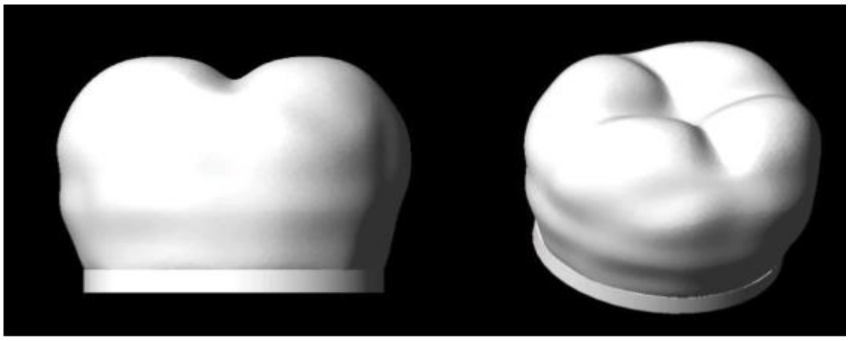

Figure 3: Crown 3D Design

Finished 3D model design of abutment and crown then imported into ANSYS software for analysis. Determination of boundary condition located at base of crown with 1 mm height. The linear homogeneous and isotropic material properties of crown materials were adjusted according to the mechanical properties (Young's modulus and Poisson's ratio) from previous literature (Table 1).

Table 1: Mechanical Properties used in FEA Model

Materials	Density (g/cm^3)	Modulus Elasticity (MPa)	Poisson Ratio
Dentin	2,10	18.600	0.31
Zirkonia	6,07	210.000	0.30
Polyetheretherketone	1,32	400	0.40
Lithium disilicate	2,43	95.000	0.23

Division of complex 3D geometries by meshing in model range 36271-49264 elements and 52214-70217 nodes represents mandibular first molar model which can be done automatically in ANSYS. Tetrahedral element meshing is used for accurate FEA results. Each model is given a simulation of external load in the form of a compressive force of 600 N axially (angle 0°/vertical load) at the setup phase using ANSYS (Figure 4). Results of stress distribution obtained then analyzed and compared quantitatively and qualitatively.

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Vol: 60 | Issue: 11 | 2023

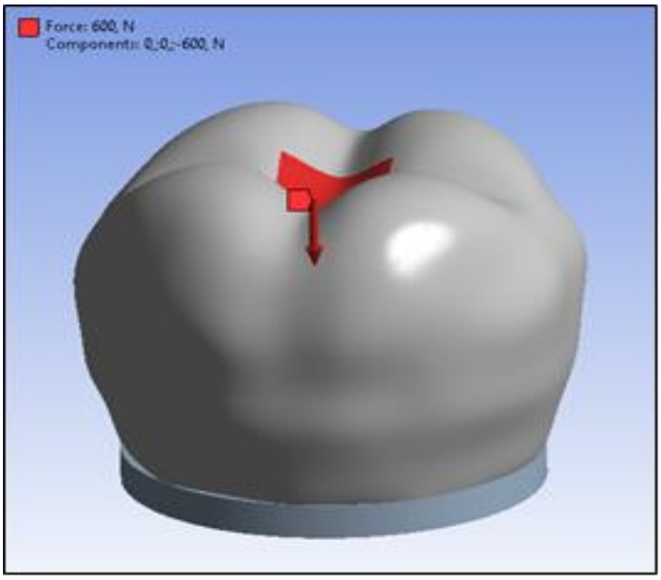
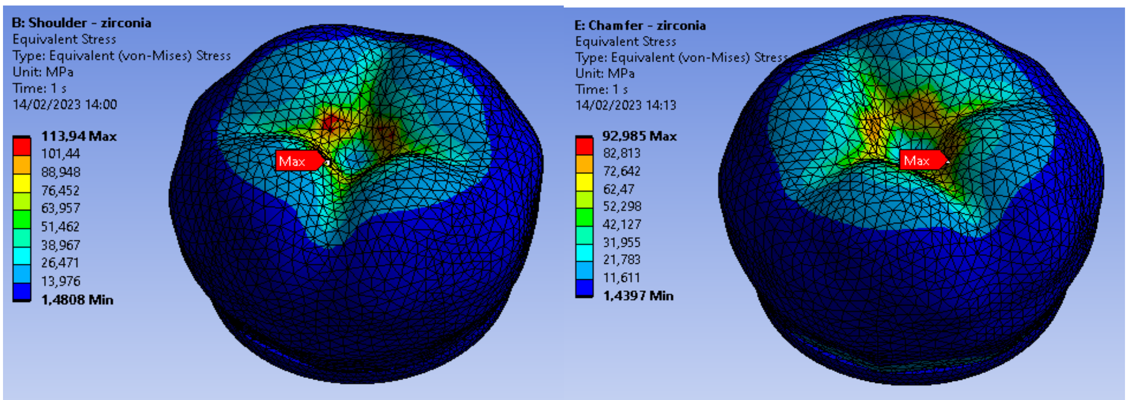


Figure 4: Simulated load direction

This research does not use real physical models and materials for simulation with finite element analysis. All material properties are mechanical properties of materials based on literature and previous studies. The 3D model is designed with software to optimize the design of crown restoration. Another advantage is that model will be more precise, minimize operator error and can be replicated by other researchers with the same size and shape.

RESULTS

Results of the analysis are obtained by looking at the value and distribution of the von Mises color contour plot as a parameter indicating the stress distribution. Stress concentration in zirconia crown with shoulder and chamfer finish line design are in the occlusal region and the axial wall of the crown. The highest stress concentration occurred in shoulder finish line design model of 113.94 MPa while in chamfer finish line design 92.985 MPa (Figure 5).



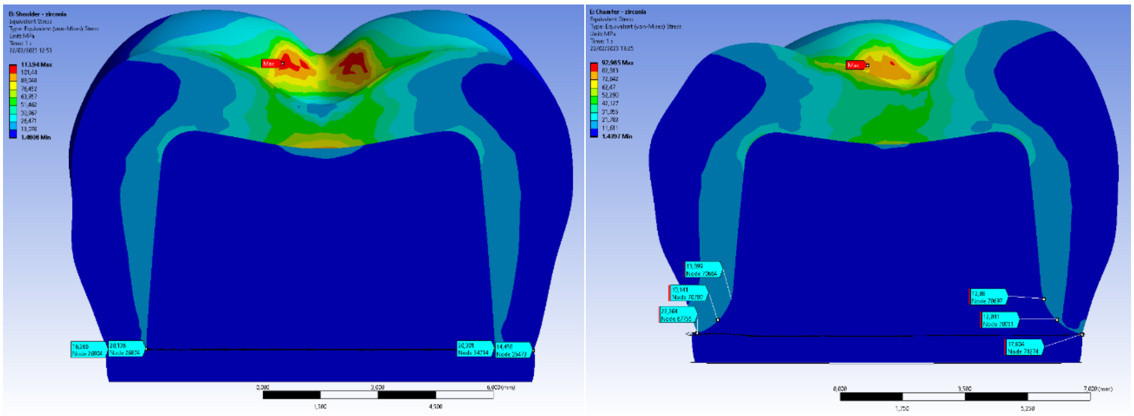
a. **b.**

Figure 5: Stress Distribution in Zirconia Crown Shoulder (a) Chamfer (b) Finish Line Design

Stress concentration at margins of zirconia crown clearly seen in chamfer finish line design than shoulder (Figure 6). Stress in zirconia crown margin increases on abutment teeth with chamfer finish line design which marked in light blue color. In zirconia crown, maximum principal stress value in the

DOI: 10.5281/zenodo.10217868
Vol: 60 | Issue: 11 | 2023

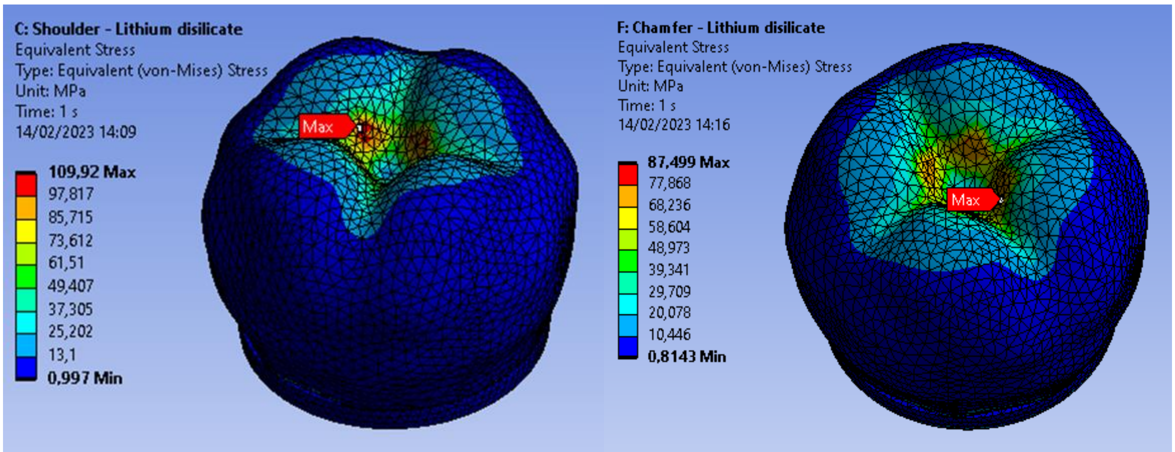
cervical area with chamfer finish line design has a maximum value of 22.264 MPa higher than shoulder finish line design of 20.301 MPa.



a. b.

Figure 6: Maximum Stress Distribution of Zirconia Crown with Shoulder (a) Chamfer (b) Finish Line Design

Stress concentration in lithium disilicate crown with shoulder and chamfer finish line design located at occlusal area and axial wall of the crown. The highest stress concentration occurred in shoulder finish line design model of 109.92 MPa while in chamfer finish line design 87.499 MPa (Figure 7).

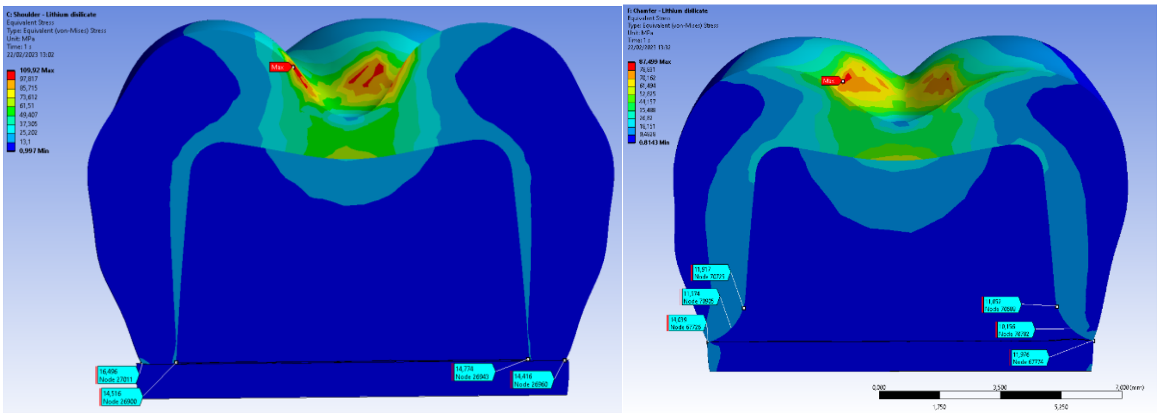


a. b.

Figure 7: Stress Distribution in Lithium Disilicate Crown Shoulder (a) Chamfer (b) Finish Line Design

Stress concentration at margin of lithium disilicate crown had the highest value in shoulder finish line design compared to chamfer (Figure 8). Stress at the margin of lithium disilicate crown increased in abutment with shoulder finish line design. In lithium disilicate crown, the maximum principal stress value in cervical area with shoulder finish line design has maximum value of 16.496 MPa higher than the maximum value of chamfer design of 14.039 MPa. The abutment teeth appear to absorb more stress in the chamfer design which is marked in light blue color in the loading fossa area.

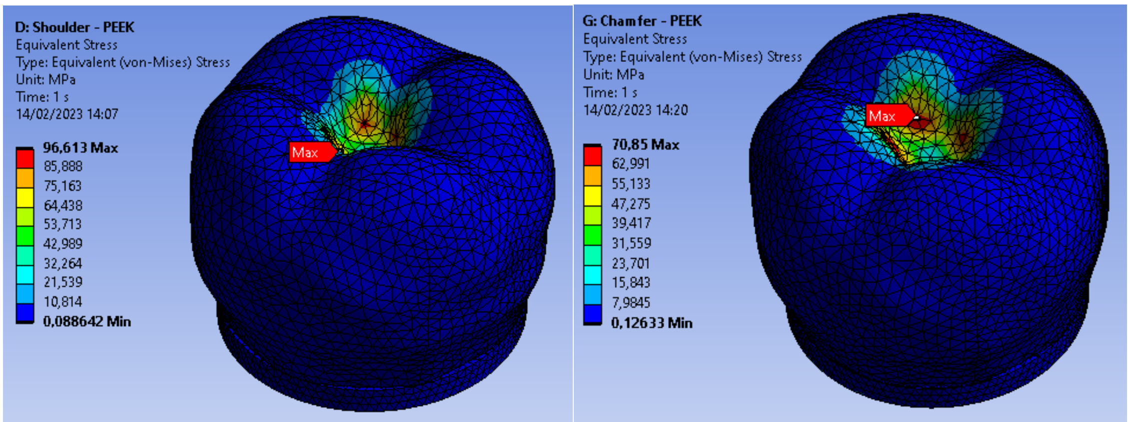
DOI: 10.5281/zenodo.10217868
Vol: 60 | Issue: 11 | 2023



a. b.

Figure 8: Maximum Stress Distribution of Lithium Disilicate Crown with Shoulder (a) Chamfer (b) Finish Line Design

Stress concentration in PEEK crown with shoulder and chamfer finish line design located at occlusal area and axial wall of the crown. The highest stress concentration occurred in shoulder finish line design model with 96.613 MPa, while in chamfer finish line design with 70.85 MPa (Figure 9).

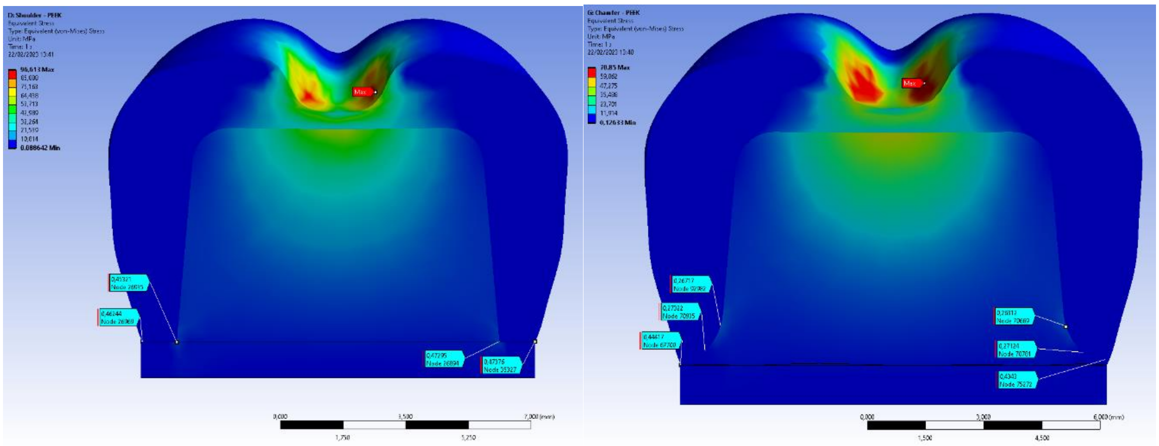


a. b.

Figure 9: Stress Distribution in PEEK Crown Shoulder (a) Chamfer (b) Finish Line Design

Stress concentration at margin of PEEK crown appeared to be almost the same in shoulder and chamfer finish line design (Figure 10). Stress at margin of PEEK crown were slightly higher in the abutment tooth with shoulder finish line design. In PEEK crown, maximum principal stress value in cervical area with shoulder finish line design has a maximum value of 0.473 MPa higher than the maximum value of chamfer finisih line design which is 0.444 MPa.

DOI: 10.5281/zenodo.10217868
Vol: 60 | Issue: 11 | 2023



a. b.

Figure 10: Maximum Stress Distribution of PEEK Crown with Shoulder (a) Chamfer (b) Finish Line Design

DISCUSSION

Finite element analysis is widely used in a lot of scopes in dental research which represents a simplification of practical scenario. In this research, a simplified tooth model used with no coefficient of friction and without pulp, root, periodontal ligament, or bone to simplify the analysis of the results. Tooth mobility degree, cement stiffness residual stresses and also errors laboratory process from crown fabrication were not considered in this research. It is assumed that all materials had a perfect union with zero internal defect in crown restoration. Limitation of this research lies in the potential effect of these elements on the stress distribution in crown restoration.

In this research, crown restoration receive stress at occlusal loading area and axial wall in the proximal and cervical area. Rocha et al (2011), Costa et al (2014), Dsouza et al (2017) and Miura et al (2018) stated that there is a large stress in the cervical area of crown under load therefore it is considered vulnerable that can initate cracks. This research also observed that crown restoration materials and finish line design influence stress distribution pattern in the restoration when a load was applied.

In zirconia crown restoration, stress distribution is concentrate in fossa region of loading area, intaglio surface of the axial wall and cervical area however abutment teeth receive few stress. The results of this research consistent with Imanishi et al, Della Bona et al, Di Lorio et al, Ha et al and Miura et al that stated in zirconia crown restoration, stress concentrate more within the restoration. This could happen because zirconia crown have a higher modulus of elasticity than abutment teeth and indicates that zirconia crown will receive and resist the maximum stress that applied before distributing it to the underlying tooth structure. In chamfer finish line design, zirconia crown in cervical area is marked with more light blue color which indicates more concentrated stress than shoulder design. It might be happened because flat areas in chamfer finish line design have been removed resulting in thinner crown margin for zirconia material thereby reducing the ability to receive vertical loading stress. According to Oh et al (2002), the vertical force that generally applied induces cracks from the fragility of ceramic caused by the tensile stress. In shoulder finish line design, thickness of zirconia crown material increased which may increase the durability of the restoration so that the stress values are recorded lower. Denry & Kelly (2008) stated that fractures in zirconia materials rarely occur when the material has sufficient thickness. For that reason, better durability of zirconia crown can be expected with shoulder finish line design.

DOI: 10.5281/zenodo.10217868
Vol: 60 | Issue: 11 | 2023

Lithium disilicate crown receive stresses within the restoration and transfer it slightly to the abutment teeth. This can happen because of lithium disilicate material which has a lower modulus elasticity. Stresses in the cervical area of lithium disilicate crown marked with more homogeneous light blue color in chamfer finish line design while in shoulder finish line design, stresses were marked with dark blue with light blue color on the outer edge restoration. Chamfer finish line design distribute stress more evenly and might have compensated for the flexibility of lithium disilicate material. Therefore, stresses were recorded slightly higher in shoulder finish line design than chamfer design. In this analysis, lithium disilicate crown restoration with chamfer finish line design expected to increase longer durability of restoration due to a more uniform stress distribution from occlusal loads. The results of this analysis are in accordance with Magray et al (2018) which stated that chamfer finish line design on lithium disilicate premolar crown distribute stress more evenly so that lower stress values are noted.

PEEK crown restoration receive stresses in the restoration and transfer stresses to the abutment teeth. This can happen because of PEEK material which has a lower modulus elasticity. The results of this analysis are in accordance with the properties of PEEK that can absorb shock, stresses were seen being absorbed first then distributed towards the abutment teeth. The deformation properties and flexibility of PEEK crown in receiving stress occur when a stress is applied. This affect the results of the PEEK crown restoration simulation. According to Biyao et al (2022), PEEK materials have compressive strength comparable to teeth and low density (1.4g/cm3), so that PEEK can distribute stress more evenly. With small differences in the maximum stress values at crown cervical region, PEEK crown with chamfer finish line design may have a design structure that supports PEEK crown to accept stress better. Chamfer finish line design appears to absorb stress more evenly and widens it which marked by a lighter color intensity; yellow, orange to tosca blue compared to shoulder finish line design with a darker color intensity; yellow, green to blue tosca. PEEK crown with chamfer finish line design are expected to distribute stresses better therefore can increase their durability. The nature of the PEEK material as a polymer-based material with a modulus of elasticity of 4-6 GPa close to bone is the reason that PEEK crown can absorb stress better. PEEK crown shows exciting prospect and additional advantages due to the material properties. This analysis also provides additional information on PEEK research in dentistry which are still not widely explored.

In this research, FEA results demonstrated that differences in finish line and crown restoration materials clearly affect the stress distribution in crown restorations. The maximum stress value in crown cervical area with shoulder finish line design has the highest value and decreases with chamfer finish line design except for zirconia crown. Each shoulder finish line design of the restoration appears to transmit stress less evenly compared to chamfer design. Zirconia crown with chamfer finish line design are susceptible to greater stresses. Lithium disilicate and PEEK crown have better stress distribution with chamfer finish line design. Zirconia and lithium disilicate crown restorations receive stresses within the restoration before transfering stresses to the abutment teeth. In contrast, PEEK crown absorbed stress and transfer directly to the abutment teeth.

The amount of stress in crown restorations from highest to lowest value if sorted begin with zirconia, lithium disilicate and PEEK crown. This sequence coincides with the value of the modulus elasticity they owned. The greater the modulus of elasticity of the crown restorative material, the higher the stress values observed in the restoration, regardless of the type of finish line design used. This result is in accordance with the study of Mizusawa et al, namely the higher the material properties of a crown restoration, the higher the stress concentrated in the cervical area of the crown restoration. According to Attia (2018), stress distribution in crown restoration depends on the nature of the material and geometric configuration. The elastic modulus of the material is an important parameter.

DOI: 10.5281/zenodo.10217868
Vol: 60 | Issue: 11 | 2023

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.

CONCLUSION

Results of this research simulation can be concluded that:

1. Zirconia posterior crown had the highest maximum stress value with 22.264 MPa in chamfer finish line design compared to shoulder finish line design. Shoulder finish line design is expected to distribute stress better on zirconia crown restoration for longer durability of the restoration.
2. Lithium disilicate posterior crown had the highest maximum stress value with 16.496 MPa in shoulder finish line design compared to chamfer finish line design. Chamfer finish line design is expected to distribute stress better on lithium disilicate crown restoration for longer durability of the restoration.
3. PEEK posterior crown had the highest maximum stress value with 0.473 MPa in shoulder finish line design compared to chamfer finish line design. Chamfer finish line design is expected to distribute stress better on PEEK crown restoration for longer durability of the restoration.
4. Stress distribution in posterior crown noted to be increase in stress value at cervical region of the crown along with the increase in restorative material modulus of elasticity. The difference in stress distribution between zirconia, lithium disilicate and PEEK crown can be seen in the stress distribution of PEEK crown which spread more evenly and prevents stress concentration in the cervical region of the crown.

Zirconia crown with shoulder finish line design and lithium disilicate crown with chamfer finish line design distribute stress better by transferring the stress inside the restoration, while PEEK crown with chamfer finish line design distribute stress better by absorbing the stress and transfer it to the abutment teeth. PEEK crown restoration can be consider for clinical use as an alternative restorative material.

References

1) Attia, M. A. (2018). Effect of Material Type on the Stress Distribution in Posterior Three-Unit Fixed Dental Prosthesis: A Three-Dimensional Finite Element Analysis. Egyptian Dental Journal, 64(4), 3907–3918.

2) Beuer F., Aggstaller, H., Edelhoff, D., & Gernet, W. (2008). Effect of preparation design on the fracture resistance of zirconia crown copings. Dental Materials Journal, 27(3), 362–367.

3) Rosentsiel SF, Land MF, Fujimoto (2016). Contemporary Fixed Prosthodontics. 5th ed. St.Louise : Elsevier.

4) H.Ralph, A. K. J. S. C. R. (2003). Phillips' Science of Dental Materials. Elsevier. https://www.ptonline.com/articles/how-to-get-better-mfi-results

5) Jalalian, E., & Aletaha, N. S. (2011). The effect of two marginal designs (chamfer and shoulder) on the fracture resistance of all ceramic restorations, Inceram: An in vitro study. Journal of Prosthodontic Research, 55(2), 121–125.

DOI: 10.5281/zenodo.10217868
Vol: 60 | Issue: 11 | 2023

6) Costa, A., Xavier, T., Noritomi, P., Saavedra, G., & Borges, A. (2014). The Influence of Elastic Modulus of Inlay Materials on Stress Distribution and Fracture of Premolars. Operative Dentistry, September.

7) Skjold, A., Schriwer, C., & Øilo, M. (2019). Effect of margin design on fracture load of zirconia crowns. European Journal of Oral Sciences, 127(1), 89–96.

8) Türk, A. G., & Ünal, S. (2016). The effect of marginal preparation type on an all ceramic anterior crown: A finite element study. Cumhuriyet Dental Journal, 19(3), 214–221.

9) Hsu, M.-L., & Chang, C.-L. (2010). Application of Finite Element Analysis in Dentistry. Finite Element Analysis, May.

10) Trivedi, S. (2014). Finite element analysis: A boon to dentistry. Journal of Oral Biology and Craniofacial Research, 4(3), 200–203.

11) Rocha. Mechanical behavior of ceramic veneer in zirconia-based restorations: A 3-D finite element analysis using microcomputed tomography data. J Prosthet Dent 2010; 105: 14-20.

12) Dsouza KM, Aras MA. Three-dimensional finite element analysis of the stress distribution pattern in a mandibular first molar tooth restored with five different restorative materials. J Indian Prosthodont Soc 2017; 17:53-60.

13) Jalali, H., Sadighpour, L., Miri, A., & Shamshiri, A. R. (2015). Comparison of Marginal Fit and Fracture Strength of a CAD/CAM Zirconia Crown with Two Preparation Designs. Journal of Dentistry (Tehran, Iran), 12(12), 874–881.

14) Rammersberg P, Eickemeyer G, Pospiech P. Fracture resistance of posterior metal free polymer crowns. J Prosthet Dent 2000; 84:14–32.

15) Cho L, Choli J, Yi YJ, Park CK. Effect of finish line variants on marginal accuracy and fracture strength of ceramic optimized polymer/fiber-reinforced composite crowns. J Prosthet Dent 2004.

16) Potiket Potiket N, Chiche G, Finger IM. Invitro fracture strength of teeth restored with different all ceramic crown systems. J Prosthet Dent 2004.

17) Roh HS, Woo YH, Pae A. Full mouth rehabilitation with pressed ceramic technique using provisional restorations. Pressed ceramic technique. J Korean Academy Prosthodont. 2013; 51:47-51.

18) Ahmadzadeh, A., Golmohammadi, F., & Mousavi, N. (2015). Effect of Marginal Design on Fracture Resistance of IPS e.max all Ceramic Restorations : Chamfer Versus Shoulder Finish Lines. Journal of Islamic Dental Association of IRAN (JIDAI) spring, 7(2), 64–69.

19) De Jager N, Pallav P, Feilzer AJ. The influence of design parameters on the FEA-determined stress distribution in CAD/CAM produced all ceramic dental crown. Dent Mater 2005; 21:242–51.

20) Di Iorio D, Murmura G, Orsini G, Scarano A, Cupatis. Effect of margin design on the fracture resistance of procera all ceramic cores: an in vitro study. J Contemp Dent Pract 2008; 9:1–8.

21) Miura, S., Kasahara, S., Yamauchi, S., & Egusa, H. (2018). Effect of finish line design on stress distribution in bilayer and monolithic zirconia crowns: a three dimensional finite element analysis study. European Journal of Oral Sciences, 126(2), 159–165.

22) Magray et al. Influence of shoulder and chamfer margin design on the stress distribution pattern in different all ceramic restorations by three-dimensional finite element analysis. On J Dent & Oral Health. 2018; 1(3): 1-6.

DOI: 10.5281/zenodo.10217868
Vol: 60 | Issue: 11 | 2023

23) Shilingburg HT, Sumiya H, Whitsett LD, Jucobi R, Bruckett SE (2012). Fundamentals of Fixed Prosthodontics. 4th ed. Chicago: Quintessence.

24) Saint-Jean, S. J. (2014). Dental Glasses and Glass-ceramics. In Advanced Ceramics for Dentistry. Elsevier Inc. https://doi.org/10.1016/B978-0-12-394619-5.000122

25) Goodacre CJ, Bernal G., Rungcharassaeng, K., & Kan, J. Y. K. (2000). Clinical complications in fixed prosthodontics. The Journal of Prosthetic Dentistry,July, 31–41.

26) Arif A., Haji Z., Ghafoor R. (2022). Sneak Peek on Polyetheretherketone (PEEK) in Dentistry- A Narrative Review. Biomed J Sci & Tech Res, 44(2), 35335–35343.

27) Imanishi A, NaKamura T, Ohyama T, Nakamura T. 3D finite element analysis of all ceramic posterior crowns. J Oral Rehabil 2003; 30:818–22.

28) Della Bona, Á. Borba, M., Benetti, P., Duan, Y., & Griggs, J. A. (2013). Three dimensional finite element modelling of all-ceramic restorations based on micro CT. Journal of Dentistry, 41(5), 412–419.