IDR International Dental Research

Original Article

The effect of occlusal reduction and different CAD-CAM materials on stress distribution in endocrown restorations: A three-dimensional finite element analysis

Gökçen İrem Tolu[1], Neslihan Güntekin[1], Reza Mohammadi[2], Mehmet Gökberkkaan Demirel[1]

[1] Necmettin Erbakan University, Faculty of Dentistry, Department of Prosthodontics, Konya, Turkey
[2] Necmettin Erbakan University, Faculty of Dentistry, Konya, Turkey

Correspondence:

Dr. Gökçen İrem TOLU
Necmettin Erbakan University, Faculty of Dentistry, Department of Prosthodontics, Konya, Turkey
E-mail: dt.gokcentolu@hotmail.com

Received: 12 October 2022
Accepted: 10 December 2022

Access Online

DOI: https://doi.org/10.5577/intdentres.461

Abstract

Aim: The aim of this study was to examine the effects of various preparation types and restorative materials on endocrown restorations applied to endodontically treated maxillary first molars and the stress distribution on the related tissues.
Methodology: A three-dimensional (3D) image of a previously extracted intact tooth was obtained with CBCT. The resulting .dicom files were imported into Mimics. Enamel, dentine, and pulp were separated and extracted as an STL file. Four groups were determined and prepared in SolidWorks. The 3D images were imported into the relevant finite element analysis software (ABAQUS, 2020 Dassault Systems Simulation Corp., Johnston, RI, USA), and a load of 600 N was applied at the occlusal area of each model in the axial direction. Models were divided into three groups according to material type: Vita Suprinity (VS; VITA Zahnfabrik, Bad Sackingen, Germany), Cerasmart (CS; GC Corp., Tokyo, Japan), and Shofu Block HC (SB; Shofu, Kyoto, Japan). The type of cement used was RelyX ARC (3M ESPE, MN, USA).
Results: Regardless of the results, stress on any tissue or restoration did not exceed the strength limits. In models with cusp preparation, the stress on the dental tissues was lower. Higher stress was generally observed in groups in which the lingual area was healthy. On the other hand, stress occurring in zirconia-reinforced glass ceramics (VS) is higher than in ceramic materials with a resin matrix (CS, SB). It has been determined that the stress transmitted to the supporting tissues is lower.
Conclusion: Endocrown restorations can be used in the restoration of endodontically treated first molars. In addition, when endocrown restoration is applied to molars with only one healthy area and excessive loss of coronal structure, reducing the cusp is beneficial in terms of the distribution of stress on healthy tissues.

Keywords: Cone-beam computed tomography, CAD-CAM, endocrown, finite element analysis, glass ceramic, resin matrix ceramic

How to cite this article: Tolu Gİ, Güntekin N, Mohammadi R, Demirel MG. The effect of occlusal reduction and different CAD-CAM materials on stress distribution in endocrown restorations: A three-dimensional finite element analysis. Int Dent Res 2022;12(Suppl.1):22-8. https://doi.org/10.5577/intdentres.461

Introduction

Extensive use of computer-aided technology in dentistry recently has led to significant changes in clinical practice (1). Computer-aided technologies facilitate the fabrication of full or partial crowns with a high level of accuracy to meet the expectations of patients and physicians regarding aesthetic appearance. New therapeutic approaches that entail fabricating monoblock structures, such as endocrowns, have emerged as a result of digital advances and the growing importance of minimally invasive dentistry.

Endocrowns are monoblock restorations extending into the pulp chamber, and are used to reconstruct endodontically treated teeth (2). The stress caused by the posts inside the root and the cases where dental post application is not possible, especially when the roots are excessively curved or short, have generalized the use of endocrown restorations. In addition, endocrown restorations can be prepared in a single session, which is a significant benefit. Previous studies reported that, endocrowns have adequate stability, higher fracture resistance (3, 4), and a 94-100% success rate compared to conventional restorations (5). Endocrowns are retained mainly through the axial walls and pulp chamber, while the cement and the restoration fabricated based on the preparation serve as support (3).

Computer-aided design and computer-aided manufacturing (CAD-CAM) materials have been introduced with improved mechanical properties and excellent optical characteristics (6). Ceramic restorations have become extremely popular due to their aesthetic features, biocompatibility, and durability. However, they also have disadvantages, such as the potential for fracture and causing excessive wear on the opposing tooth. For this reason, newly developed resin-matrix ceramic materials have been introduced to benefit from both the flexibility of the resin material and the aesthetic features of ceramics (7). These materials have several advantages, such as being easy to process and not requiring additional applications. They also have good dimensional stability (8), biomimetic properties similar to the structure of teeth (9), and good stress distribution (10).

Lithium disilicate with zirconium oxide has recently been introduced. It offers better mechanical properties than lithium disilicate alone (11). This structural typology was combined to achieve more favorable optical properties and mechanical characteristics than other glass ceramics (12). Previous studies have demonstrated that its fracture resistance is also superior (13, 14).

FEA numerically simulates the behavior of various dental restorations, biomaterials, restorative techniques, and prosthetic designs stress distribution under different loading situations. It allows the assessment and quantification of the biomechanical response of complex dental structures (15).

Stress distribution analysis should be carried out to accurately evaluate the applicability of endocrowns in molars. Previous studies focused on the effect of the amount of remaining tooth and restorative material on fracture resistance (16). However, the relevant literature lacks sufficient information on the effect of cusp reduction in the remaining wall on fracture resistance. Although the elastic modulus of newly developed dental materials ranges from 10 to 250 GPa, their effect on the stress distribution in teeth restored with endocrowns is not certain. Finite element analysis is frequently carried out to examine stress distribution in dental biomechanical studies (10, 17-20).

The current study aimed to examine the effect of occlusal reduction on stress distribution in endocrown restorations and supporting dental tissues. The null hypothesis is that occlusal reduction or different materials will not affect the stress distribution on the restoration and tooth.

Materials and Methods

The 3D geometry of tooth 26, which was taken with a dental tomography (DA1) device, was scanned. Cone-beam computerized tomography (CBCT) was performed using Morita 3D Accuitomo 170 (J Morita Mfg. Corp., Kyoto, Japan). The size of the imaging volume was a cylinder with a diameter of 40 mm × height of 40 mm at the X-ray rotational center. Images were taken under exposure conditions of 90 kVp (X-ray tube voltage) and 5 mA (value of the electric current), which are standard parameters and can be changed for different subjects. Images were taken using 160 qm and 17.5-second exposure time. The 3D geometry created using Geomagic Design X 2020.0 software was divided into surfaces, and necessary arrangements were applied. As the periodontal ligament (PDL) was not designed, fixed and pinned boundary conditioning was used to simulate roots as fixed in the bone. The tooth model was placed in the coordinate system in such a way that the x-axis defines the buccolingual direction, the y-axis defines the mesiodistal direction, and the z-axis is oriented upward (Fig. 1).

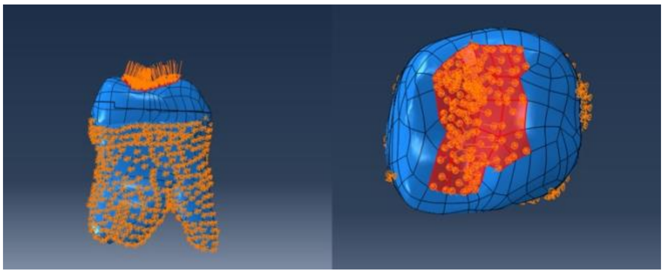

Figure 1. Load and boundary conditions

The following four groups were modeled with SolidWorks 2013 software (SolidWorks Corp., USA): Group 1: only the buccal wall is fully intact, and the cusp is not prepared (BCI); Group 2: only the buccal wall is intact, and the cusp is prepared (BCP); Group 3: only the lingual wall is fully intact, and the cusp is not prepared (LCI); and Group 4: only the lingual wall is intact, and the cusp is prepared (LCP). Since the elastic modulus and Poisson ratio of different ceramic materials affect the stress values on dental tissues and restoration materials, the mechanical properties of the materials (elastic modulus and Poisson ratio; Table 1) were determined from published values and the probability of failure. We used three CAD-CAM materials in the current study: Vita Suprinity (VS; VITA Zahnfabrik), Cerasmart (CS, GC Corp.), and Shofu Block HC (SB; Shofu). The type of cement used was RelyX ARC (3M ESPE). The compressive strength of the various materials and testing data for calculation were adopted from the literature (Table 1).

Stress distribution was examined using Abaqus software and the finite element stress analysis method. The restorative materials used in our study were included in the simulation as isotropic, linear elastics. Periodontal ligament and jawbone were not included in the analysis. A total load of 600 N was applied to the models on the occlusal table (Fig. 2). The total number of nodes of the groups are shown in Table 2.

Table 1. Mechanical properties of the materials and structures used in this study

Material	Elastic modulus (GPa)	Poisson rate	Compressive strength (Mpa)
Dentin	18.6	0.31	282
Enamel	84	0.33	321
Gutta-percha	0.69($\times10^{-3}$)	0.45	-
Vita Suprinity (VS)	104.9	0.21	540
Cerasmart (CS)	9.6	0.306	440
Shofu Block HC (SB)	8.8	0.38	420
RelyX ARC	5.1	0.27	-

GPa: Gigapascal; MPa; Megapascal

Table 2. Nodes and elements of the tested groups

Model	Total Elements	Total Nodes	Mesh Type
BCI	4392571	1088212	Linear tetrahedral elements of C3D4
BCP	4643646	878229	Linear tetrahedral elements of C3D4
LCI	4383837	828727	Linear tetrahedral elements of C3D4
LCP	4442855	937246	Linear tetrahedral elements of C3D4

BCI: buccal wall is fully intact, and the cusp is not prepared; BCP: buccal wall is intact, and the cusp is prepared; LCI: lingual wall is fully intact, and the cusp is not prepared; LCP: lingual wall is intact, and the cusp is prepared

Results

Regarding the stress on enamel, the nonreduced cusp groups showed generally higher stress on the enamel surface where the restoration was seated, while the reduced cusp groups showed more stress on the margin formed on the relevant wall (Fig. 2). When the materials were compared, the material with a higher elastic modulus (zirconium-reinforced lithium disilicate glass ceramics, VS) demonstrated better results, and the stress value for each group was lower than for the other materials. No significant difference was found between CS and SB compared to VS. Generally, a higher stress distribution was measured in the enamel of the groups for which the cusps were not prepared. In general, a lower level of stress was measured for the enamel in cases where the nonfunctional buccal cusp was healthy compared to the group with a healthy functional lingual cusp (Fig. 3).

Regarding the stress exerted on restorations, the nonreduced cusp groups generally showed higher stress at the junction of the enamel and the restoration. On the other hand, the reduced cusp groups showed higher stress on the occlusal plate (Fig. 4), and their restoration showed more stress compared to the nonreduced cusp groups (Fig. 5). The groups in which VS was used generally showed a higher level of stress on the restoration than did those with ceramics with resin. No significant difference was established between CS and SB (Table 3).

When the risk of enamel and restoration fracture was calculated, no significant difference was found between restorations in groups with healthy nonfunctional cusps. In groups that received a load on the functional cusp, the risk of fracture of the restoration was higher in those with VS. The risk of fracture in enamel was higher in the CS and SB models (Table 4).

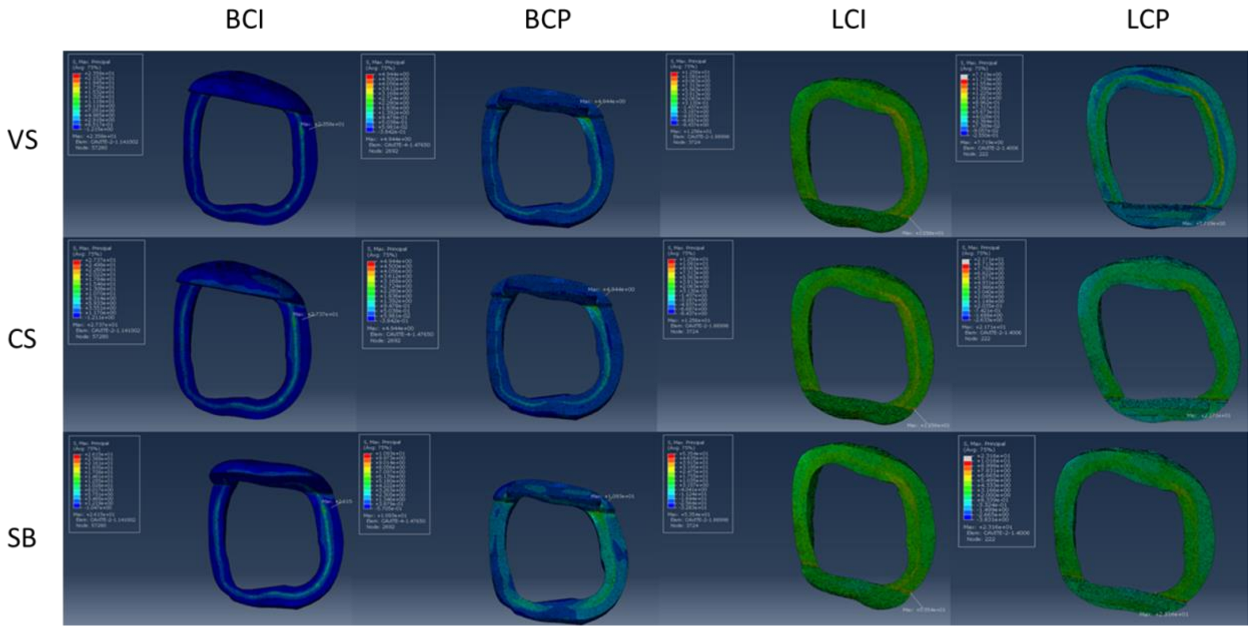

Figure 2. Patterns of maximum principal stress distribution under a force of 600 N, by restorative material type for enamel

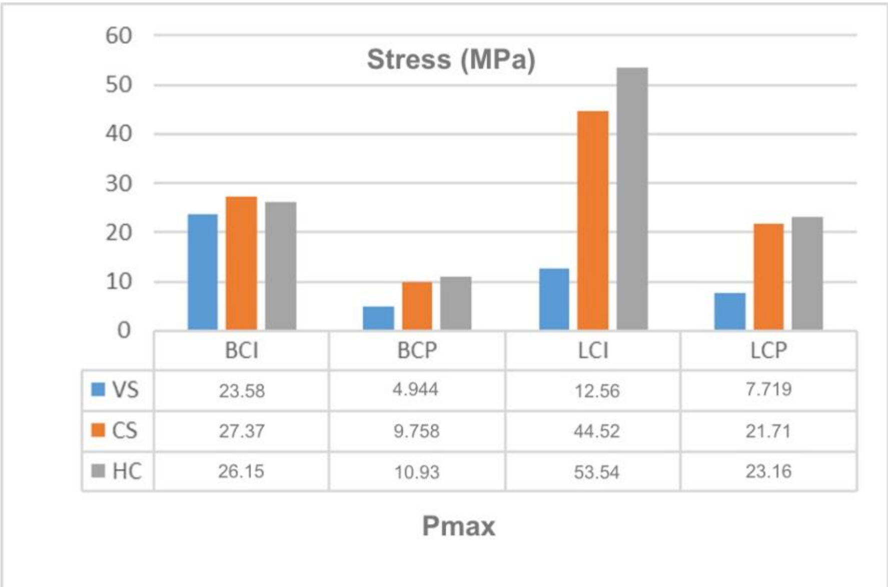

Figure 3. Graphical representation of maximum principal stress values for enamel

Table 3. Maximum principal stress (MPa) values in enamel and restoration by materials

Material		Group			
		BCI	BCP	LCI	LCP
Enamel	VS	23.58	4.944	12.56	7.719
	CS	27.37	9.758	44.52	21.71
	SB	26.15	10.93	53,54	23.16
Restoration	VS	2.348	3.003	4.31	2.943
	CS	1.909	2.864	1.079	2.008
	SB	1.776	2.601	1.074	1.993

BCI: buccal wall is fully intact, and the cusp is not prepared; BCP: buccal wall is intact, and the cusp is prepared; LCI: lingual wall is fully intact, and the cusp is not prepared; LCP: lingual wall is intact, and the cusp is prepared; VS: Vita Suprinity; CS: Cerasmart; SB: Shofu Block HC

Table 4. Probability of failure by material

Material		Group			
		BCI	BCP	LCI	LCP
Enamel	VS	0.0735	0.0154	0.0391	0.0241
	CS	0.0853	0.0304	0.1387	0.0676
	SB	0.0815	0.0341	0.1668	0.0735
Restoration	VS	0.0043	0.0056	0.0079	0.0054
	CS	0.0044	0.0065	0.0024	0.0046
	SB	0.0042	0.0062	0.0026	0.0047

BCI: buccal wall is fully intact, and the cusp is not prepared; BCP: buccal wall is intact, and the cusp is prepared; LCI: lingual wall is fully intact, and the cusp is not prepared; LCP: lingual wall is intact, and the cusp is prepared; VS: Vita Suprinity; CS: Cerasmart; SB: Shofu Block HC

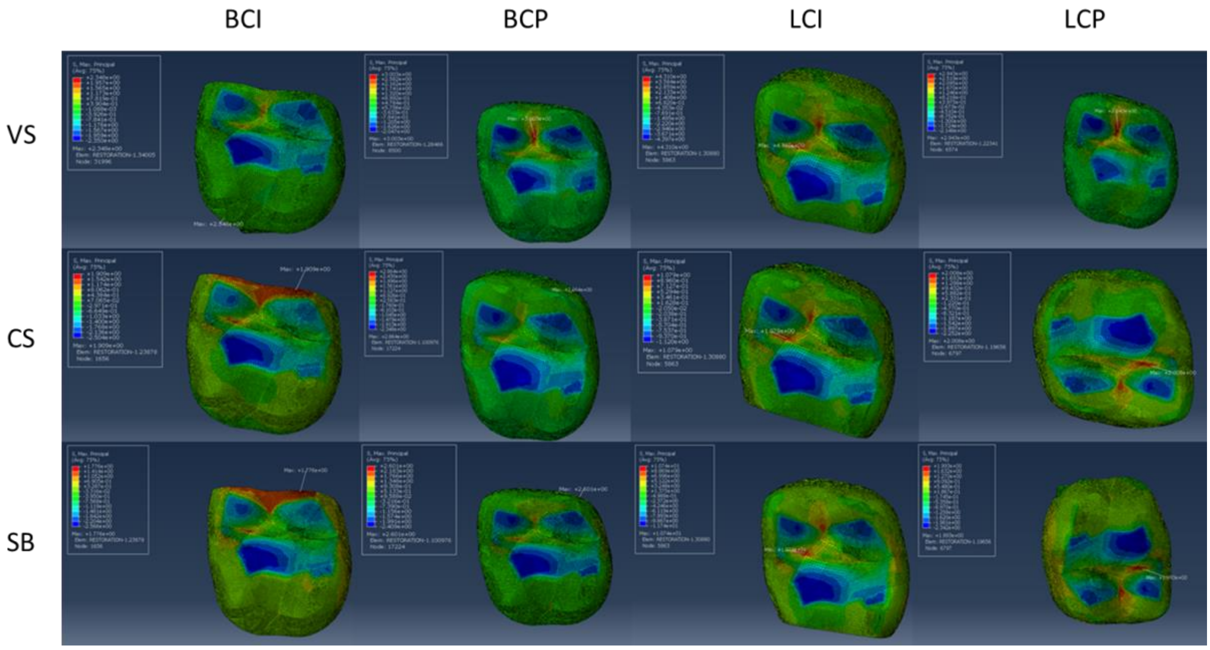

Figure 4. Patterns of maximum principal stress distribution under a force of 600 N, by restorative material type for restoration

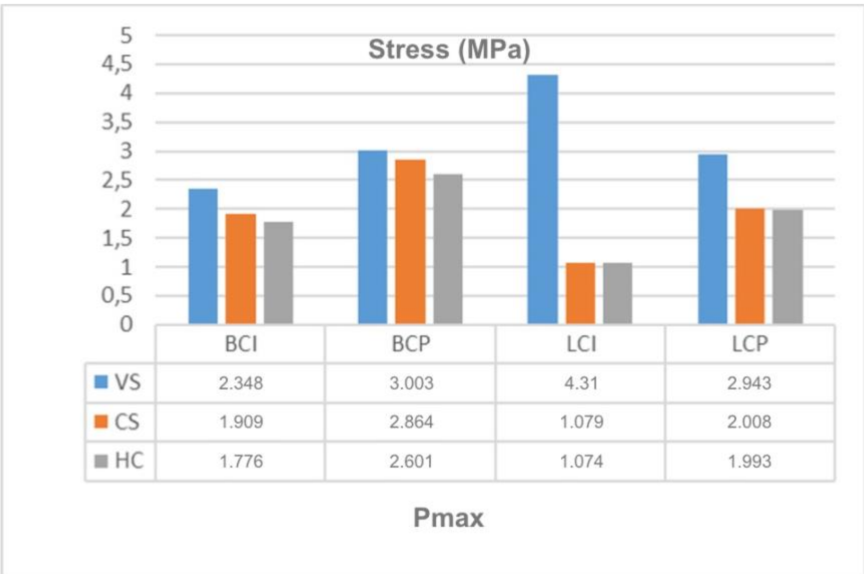

Figure 5. Graphical representation of maximum principal stress values for restoration

Discussion

The present study demonstrated that cusp reduction and restoration materials affect the magnitude and distribution of stress in dental tissues and restorations. Therefore, the null hypothesis was rejected.

Finite element analysis is a dental biomechanical method used to predict stress distribution in oral tissues and the clinical performance of restorative materials (21). It is one of the most effective approaches to simulating oral tissues in vitro. The present study carried out finite element analysis to investigate the stress distribution on different CAD/CAM ceramic restorations and various endocrown preparations. Maximum principal stress is an accurate indicator for predicting clinically acceptable conditions and damage to oral tissues and restorative materials. The results of the finite element analysis showed that the material type affected the stress distribution on molar endocrowns.

The normal masticatory force was calculated to be between 222 and 445 N (mean 322.50 N), and the highest force was 520 to 800 N (mean 660 N) in the molar region (22). Considering the occlusal loads in the molar region, the risk of fracture for the restorative materials was between 0.24% and 0.79%. The highest risk of fracture was found for the VS material with a nonreduced and functional cusp.

Maximum principal stress levels were higher in VS with a higher elastic modulus than in resin matrix ceramics (23,24). We observed that resin-matrix ceramics (CS and SB) with more elastic modulus properties had a lower risk of fracture compared to VS material. This observation may suggest that endocrowns fabricated from resin-matrix ceramics, which provide better stress distribution, can be used for longer periods (10,25). However, the present study also demonstrated that VS material transmits a lower level of stress to enamel. We can therefore assume that the failures that may occur in endocrown restorations fabricated from resin-matrix ceramics will also be catastrophic (26).

In our study, the restoration showed higher stress in the groups for which the cusps were prepared. Maximum principal stress values were higher in restorations covering dental cusps (19), and the risk of failure was calculated to be lower, especially in cases where the functional cusp was covered. The lower levels of principal stress may be the result of better stress distribution and masticatory forces not being transmitted directly to the restoration-tooth junction.

This phenomenon is supported by previous finite element analysis studies (19, 27). This is because stress peaks were observed in the occlusal plate in reduced cusp groups, while stress peaks occurred in the enamel-restoration junction in non-prepared cusp groups. Stress peaks located on the junction surfaces may cause more severe conditions as they have a greater risk of damaging both the cement layer and the remaining tooth (28). This situation may be the reason for the higher risk of failure in non-reduced cusp groups, and this phenomenon revealed a similar result to previous research (29). Stress peaks are observed in the proximal margin regions for materials with the lower elastic modulus (CS, SB). The risk of fracture in enamel in the remaining tooth is high due to this stress distribution, which can cause microleakage from the restoration-tooth junction and chipping at the restoration margins (19).

A solid model was not created before carrying out finite element analysis, and all models were created with computer software, which might be considered a limitation of the current study. In addition, finite element analysis cannot achieve material properties in a completely realistic way. Restoration and tooth are assumed to perfectly adhere to each other, and all potential errors that might occur during the fabrication of materials are ignored. For future research, we recommend validating the results by supporting them with material research.

Conclusions

We have drawn the following conclusions based on this FEA study:

1. Considering the analysis of fractures and the stress distribution on restoration and enamel, the present study recommends the use of zirconium-reinforced lithium disilicate glass-ceramic materials in endocrown restorations to avoid the risk of catastrophic failure, despite its limitations.
2. Occlusal reduction of the functional cusp will result in better stress distribution in endocrown restorations.

Acknowledgments: This study has been presented at the Necmettin Erbakan University 2nd International Dentistry Congress in Konya, Turkey held between October 1-3, 2022.

Peer-review: Externally peer-reviewed.

Author Contributions: Conception – G.İ.T.; Design – G.İ.T., N.G.; Supervision – G.İ.T.; Materials – G.İ.T., R.M.; Data Collection and/or Processing – G.İ.T., M.G.D.; Analysis and/or Interpretation – N.G.; Literature Review – G.İ.T., M.G.D.; Writer – G.İ.T.; Critical Review – G.İ.T.

Conflict of Interest: No conflict of interest was declared by the authors.

Financial Disclosure: The authors declared that this study has received no financial support.

References

1. van Noort R. The future of dental devices is digital. Dent Mater. 2012;28(1):3-12. https://doi.org/10.1016/j.dental.2011.10.014
2. Taha D, Spintzyk S, Sabet A, Wahsh M, Salah T. Assessment of marginal adaptation and fracture resistance of endocrown restorations utilizing dif-ferent machinable blocks subjected to thermomechanical aging. J Esthet Restor Dent. 20181;30(4):319-28. https://doi.org/10.1111/jerd.12396

3. Biacchi GR, Basting RT. Comparison of fracture strength of endocrowns and glass fiber post-retained conventional crowns. Oper Dent. 2012;37(2):130-6. https://doi.org/10.2341/11-105-L
4. Dietschi D, Duc O, Krejci I, Sadan A. Biomechanical considerations for the restoration of endodontically treated teeth: a systematic review of the literature, Part II (Evaluation of fatigue behavior, interfaces, and in vivo studies). Quintessence Int. 2008;39(2):117-29.
5. Sedrez-Porto JA, Rosa WL de O da, da Silva AF, Münchow EA, Pereira-Cenci T. Endocrown restorations: A systematic review and meta-analysis. J Dent. 2016;52:8-14. https://doi.org/10.1016/j.jdent.2016.07.005
6. Spitznagel FA, Boldt J, Gierthmuehlen PC. CAD/CAM Ceramic Restorative Materials for Natural Teeth. J Dent Res 2018;97(10):1082-91. https://doi.org/10.1177/0022034518779759
7. Taha D, Spintzyk S, Schille C, Sabet A, Wahsh M, Salah T, et al. Fracture resistance and failure modes of polymer infiltrated ceramic endocrown restorations with variations in margin design and occlusal thickness. J Prosthodont Res 2018;62(3):293-7. https://doi.org/10.1016/j.jpor.2017.11.003
8. Porto TS, Roperto RC, Teich ST, Faddoul FF, Rizzante FAP, Porto-Neto S de T, et al. Brittleness index and its relationship with materials mechanical properties: Influence on the machinability of CAD/CAM materials. Braz Oral Res 2019;33:26. https://doi.org/10.1590/1807-3107bor-2019.vol33.0026
9. Gresnigt MMM, Özcan M, Van Den Houten MLA, Schipper L, Cune MS. Fracture strength, failure type and Weibull characteristics of lithium disilicate and multiphase resin composite endocrowns under axial and lateral forces. Dent Mater 2016;32(5):607-14. https://doi.org/10.1016/j.dental.2016.01.004
10. Zhu J, Rong Q, Wang X, Gao X. Influence of remaining tooth structure and restorative material type on stress distribution in endodontically treated maxillary premolars: A finite element analysis. J Prosthet Dent 2017;117(5):646-55. https://doi.org/10.1016/j.prosdent.2016.08.023
11. Zarone F, Di Mauro MI, Ausiello P, Ruggiero G, Sorrentino R. Current status on lithium disilicate and zirconia: a narrative review. BMC Oral Health 2019 Jul 4;19(134). https://doi.org/10.1186/s12903-019-0838-x
12. Hamza TA, Sherif RM. Fracture Resistance of Monolithic Glass-Ceramics Versus Bilayered Zirconia-Based Restorations. J Prosthodont 2019;28(1):e259-64. https://doi.org/10.1111/jopr.12684
13. Vasiliu R-D, Porojan SD, Bîrdeanu MI, Porojan L. Effect of Thermocycling, Surface Treatments and Microstructure on the Optical Properties and Roughness of CAD-CAM and Heat-Pressed Glass Ceramics. Materials 2020;13(2):381. https://doi.org/10.3390/ma13020381
14. Kashkari A, Yilmaz B, Brantley WA, Schricker SR, Johnston WM. Fracture analysis of monolithic CAD-CAM crowns. J Esthet Restor Dent. 2019;31(4):346-52. https://doi.org/10.1111/jerd.12462
15. Tekin S, Adıgüzel Ö, Cangül S. An evaluation using micro-CT data of the stress formed in the crown and periodontal tissues from the use of PEEK post and PEEK crown: A 3D finite element analysis study. Int Dent Res 2018;8(3):144-50. https://doi.org/10.5577/intdentres.2018.vol8.no3.8
16. Serin Kalay T, Yildirim T, Ulker M. Effects of different cusp coverage restorations on the fracture resistance of endodontically treated maxillary premolars. J Prosthet Dent 2016;116(3):404-10. https://doi.org/10.1016/j.prosdent.2016.02.007
17. Diana HH, Oliveira JS, Ferro MC de L, Silva-Sousa YTC, Gomes ÉA. Stress Distribution in Roots Restored with Fiber Posts and An Experimental Dentin Post: 3D-FEA. Braz Dent J. 2016;27(2):223-7. https://doi.org/10.1590/0103-6440201600666
18. Zengingül Aİ, Göncü Başaran E, Çelik H. Finite elements analysis of stresses formed in core and spongious bone tissue by restored implanted fixed prostheses with Polyetheretherketone (PEEK) and fiber-reinforced composite. Int Dent Res 2021;11(Suppl.1):250-8. https://doi.org/10.5577/intdentres.2021.vol11.suppl1.37.
19. Dejak B, Młotkowski A. A comparison of mvM stress of inlays, onlays and endocrowns made from various materials and their bonding with molars in a computer simulation of mastication - FEA. Dent Mater 2020;36(7):854-64. https://doi.org/10.1016/j.dental.2020.04.007
20. Zheng Z, He Y, Ruan W, Ling Z, Zheng C, Gai Y, et al. Biomechanical behavior of endocrown restorations with different CAD-CAM materials: A 3D finite element and in vitro analysis. J Prosthet Dent 2021;125(6):890-9. https://doi.org/10.1016/j.prosdent.2020.03.009
21. Gulec L, Ulusoy N. Effect of Endocrown Restorations with Different CAD/CAM Materials: 3D Finite Element and Weibull Analyses. Biomed Res Int. 2017:5638683. https://doi.org/10.1155/2017/5638683
22. De Abreu RAM, Pereira MD, Furtado F, Prado GPR, Mestriner W, Ferreira LM. Masticatory efficiency and bite force in individuals with normal occlusion. Arch Oral Biol. 2014;59(10):1065-74. https://doi.org/10.1016/j.archoralbio.2014.05.005
23. Krejci I, Daher R. Stress distribution difference between Lava Ultimate full crowns and IPS e.max CAD full crowns on a natural tooth and on tooth-shaped implant abutments. Odontology 2017;105(2):254-6. https://doi.org/10.1007/s10266-016-0276-z
24. Abtahi S, Alikhasi M, Siadat H. Biomechanical behavior of endocrown restorations with different cavity design and CAD-CAM materials under a static and vertical load: A finite element analysis. J Prosthet Dent. 2022;127(4):600.e1-600.e8. https://doi.org/10.1016/j.prosdent.2021.11.027
25. Pedrollo Lise D, Van Ende A, De Munck J, Umeda Suzuki TY, Cardoso Vieira LC, Van Meerbeek B. Biomechanical behavior of endodontically treated premolars using different preparation designs and CAD/CAM materials. J Dent. 2017;59:54-61. https://doi.org/10.1016/j.jdent.2017.02.007
26. Ural Ç, Çağlayan E. A 3-dimensional finite element and in vitro analysis of endocrown restorations fabricated with different preparation designs and various restorative materials. J Prosthet Dent 2021;126(4):586.e1-586.e9. https://doi.org/10.1016/j.prosdent.2021.05.018
27. Mei ML, Chen YM, Li H, Chu CH. Influence of the indirect restoration design on the fracture resistance: a finite element study. Biomed Eng Online 2016;15:3. https://doi.org/10.1186/s12938-015-0115-4
28. He J, Zheng Z, Wu M, Zheng C, Zeng Y, Yan W. Influence of restorative material and cement on the stress distribution of endocrowns: 3D finite element analysis. BMC Oral Health 2021;21(1):495. https://doi.org/10.1186/s12903-021-01865-w
29. Sen N, Us YO. Mechanical and optical properties of monolithic CAD-CAM restorative materials. J Prosthet Dent. 2018;119(4):593-9. https://doi.org/10.1016/j.prosdent.2017.06.012