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Original Article

Influence of connector size and ceramic type on stress distribution in fixed partial denture with endocrown and inlay retainers: A finite element analysis

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ABSTRACT

Background: The present study aimed to evaluate endocrown and inlay as retainers of fixed partial denture (FPD) and to compare the effect of restoration design, ceramic type, and connector size on stress distribution using finite element analysis.

Materials and Methods: Cone-beam computed tomography of the patient was selected and entered into Catia v5-21 software for modeling. Then, FPD was designed to replace the second premolar. Three restoration materials including lithium disilicate (LDS), zirconia reinforced lithium silicate (ZLS) and Zirconia (Zr) and three connector size including 4×4, 3×4, 3×3 mm, and in terms of preparation design as both retainer endocrown (EE), both inlay (II), first premolar inlay and first molar endocrown (IE), and first premolar endocrown and molar inlay (EI). Finally, the mechanical information was entered into the Ansys software (ANSYS Inc.). Then the mesh sub-regions were defined. Finally, a force of 300 Newton was applied vertically and at an oblique. Then, the maximum stress level and its location were compared and examined among the different study groups, and finally, the data were assessed.

Results: The minimum stress level was observed in the EI-LDS with 3 × 4 connector size under vertical loading (55.1 MPa), and the highest stress level was observed in the IE-Zr with 3 × 4 connector dimension under oblique loading (558.8 Mpa). The lowest strain (0.5) was observed in the EI-Zr with 4 mm × 4 mm connector size under vertical loading. Conversely, the highest strain (4.1) was seen in the EE-LDS with a 4 mm × 3 mm connector under oblique loading.

Conclusion: Partial ceramic restorations may serve as effective conservative alternatives to conventional full crowns as retainers for posterior FPDs.

Key Words: Endocrown, fixed partial denture, inlay, lithium disilicate, zirconia, zirconia reinforced lithium silicate

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INTRODUCTION

Replacing a missing tooth with a dental implant is often considered the ideal treatment option due to its favorable long-term prognosis and conservative nature.[1] However, specific clinical conditions such as the use of bisphosphonates, uncontrolled diabetes,

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cancer-related contraindications, or economic limitations, can preclude implant placement.[2] In these scenarios, clinicians traditionally opt for a fixed partial denture (FPD), which typically requires full-crown preparations of the adjacent teeth. Such preparations usually involve the removal of more than half of the tooth structure.[3] To achieve adequate retention for full crowns, at least 4 mm of tooth structure must remain after creating sufficient clearance.[4] In many cases, achieving this requirement necessitates invasive procedures such as crown lengthening surgery, post and core build-ups, ultimately resulting in further weakening of tooth structure and supporting tissues.

Alternatively, minimally invasive restorations, such as endocrowns and inlays, require significantly less tooth preparation. These conservative approaches are especially beneficial in clinical scenarios with limited interarch space or insufficient ferrule length, eliminating the need for crown-lengthening surgery and thereby preserving tooth integrity.[5] However, despite their clinical advantages, only a limited number of studies have examined the feasibility and biomechanical performance of endocrowns as retainers for FPDs,[6-8] highlighting a clear need for further research.

An essential determinant of structural integrity in FPD restorations is the connector dimension, which ideally should be maximized to enhance mechanical strength. Nonetheless, biological considerations dictate that connectors should maintain at least 1 mm distance from the gingival tissue crest to facilitate effective plaque control and periodontal health.[9] Previous studies have consistently identified the connector area as the site of highest stress concentration in FPDs with inlay or endocrown retainers.[3,6] Consequently, establishing clear guidelines for minimum connector dimensions tailored to different ceramic materials is necessary to optimize clinical outcomes.[10,11] Furthermore, the geometry and cross-sectional design of the connector itself significantly influence fracture resistance and stress distribution in ceramic restorations.[12] Osman *et al*.[13] study showed different stress distribution between rectangular connector compared to triangular type in resin-bonded FPD; Limited studies evaluated different connector cross-sectional design of the partial restorations as the retainers of FPD.[12,13]

A variety of ceramic materials have been evaluated in similar FPD studies, including zirconia (Zr), lithium disilicate (LDS), Zr-reinforced lithium silicate (ZLS), and composite resins.[1,6-8,14] These materials exhibit substantial differences in mechanical properties, bonding capabilities, and clinical indications, directly influencing the restoration's longevity and tooth preparation requirements. Notably, previous finite element analyses (FEA) have not specifically investigated FPDs with endocrown and inlay retainers in relation to milling designs, varying connector sizes, and their compatibility with specific ceramic materials.[6,8]

Before new treatments can be clinically implemented, these issues need to be investigated in laboratory studies. FEA predicts stress and strain distributions with considering multiple variables, such as prosthesis design, load direction and magnitude, mechanical properties, and other case-specific conditions.[15] One of the most advantage of the FEA method is its ability to modeling of complex geometries and the interactions between various components of the biomechanical system facilitates a more accurate understanding of the mechanical behavior.[16] Therefore, the present study aimed to evaluate and compare the effect of retainer design (endocrown vs. inlay), ceramic material, and connector size on stress distribution within FPDs using FEA. The null hypothesis was that variations in restoration design, ceramic material, and connector size would not influence stress distribution in FPD restorations.

MATERIALS AND METHODS

In this FEA study, cone beam computed tomography images of the right maxillary first premolar, second premolar, and first molar from a young patient exhibiting normal anatomical dimensions were selected and imported into Catia v5-21 software (Dassault System). A three-unit FPD was designed to replace the second premolar. The first maxillary premolar and molar were selected as the abutment because: 1) in comparison of mandibular posterior teeth had more vertical space to form an ideal connector size and pontic height, 2) the second premolar for replacing had lower mesiodistal widths in comparison to molar teeth, that make more favorable stress and strain distribution. Four abutment preparation designs were evaluated: both abutments prepared endocrown (EE), both as inlay (II), first premolar inlay and first molar endocrown (IE), and first premolar endocrown and first molar inlay (EI) [Figure 1]. Three ceramic materials were tested: LDS (IPS e.max CAD, Ivoclar Vivadent AG), ZLS (Celtra Duo, Dentsply Sirona), and Zr (IPS e.max ZirCAD, Ivoclar Vivadent AG). Three connector cross-sectional dimensions were also assessed: 4 mm × 4 mm, 3 mm × 4 mm, 3 mm × 3 mm.

Endocrown preparations involved a 2 mm of anatomical occlusal reduction with a butt joint finish line and a 16° divergence angle. Inlay preparations were standardized with dimensions of 2 mm height, 2 mm buccolingual thickness, and 5 mm mesiodistal width for premolars, and 2 mm height, 3 mm buccolingual thickness, and 8 mm mesiodistal width for molars.[17] Class II cavity preparation in each tooth featured a 4 mm buccolingual width, 5 mm occluso-cervical height, and an 8° taper.[18] Teeth receiving endocrown were assumed to have roots filled with gutta-percha, and restorations were cemented with resin cement thickness of 100 µm.[6] Mechanical properties, including elastic modulus and Poisson's ratio, were selected based on previously validated data [Table 1].[17,19] Subsequently, the geometries were imported into Ansys software (ANSYS; Canonsburg, PA, USA.) for finite element modeling.

Meshes were optimized using tetrahedral elements following segmentation into subregions [Figure 2]. All component interfaces were considered fully bonded. Boundary conditions included fixation of root surfaces, restricting all translational and rotational degrees of freedom, whereas other surfaces remained unrestricted. Mesh convergence testing was performed to ensure accuracy, and the resultant numbers of elements and nodes per model group are summarized in Table 2.

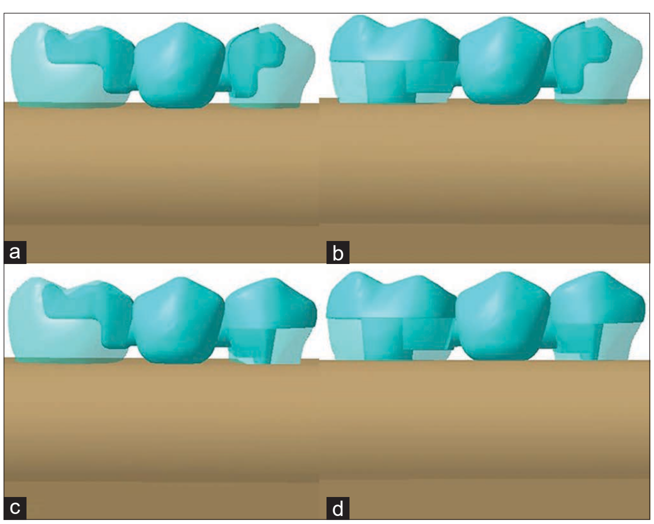

Figure 1: Study groups (a) II, (b) IE, (c) EI, and (d) EE.

As a boundary, before performing linear static analysis, the bottom area of the cortical bone cylinder was set to be fixed in place. Finally, a vertical load of 300N was applied at 45° angle targeting the lingual cusp and marginal ridges of the pontic, first premolar, and first molar, and the central fossa of the first molar [Figure 3].[6,8,17] The maximum stress values and locations were compared across different study groups.

RESULTS

The total number of elements and nodes for each finite element model group is presented in Table 2. The EI group contained the highest total number of nodes (13,84,954) and elements (841,788), whereas the II group had the lowest number of nodes (590,901) and elements (357,693).

Figure 4 summarizes the maximum principal stress values observed under vertical and oblique loading conditions. The highest principal stress (558.8 MPa) was recorded in the IE Zr restoration with a 4 mm × 3 mm connector under oblique loading. In contrast, the lowest principal stress (55.1 MPa) occurred in the EI LDS restoration with

Table 1: Poisson's ratio and elastic modulus of materials

Materials	Elastic modulus (GPa)	Poisons ration
Zirconia (IPS e.max ZirCAD)	210	0.30
ZLS (celtra duo)	108.2	0.224
LDS (IPS e.max CAD)	100	0.20
Enamel	84.10	0.33
Dentin	18.60	0.31
Pulp	0.0068	0.45
Multilink auttomix cement	5	0.29
Cortical bone	17	0/30
Spongious bone	0/35	0/25
Gutta perca	0.07	0.40

ZLS: Zirconia reinforced lithium silicate; LDS: Lithium disilicate

Table 2: The number of elements and nodes in each group

Groups	Total nodes	Total elements	Restorations nodes	Restorations elements
II	590,901	357,693	161,774	120,285
IE	656,497	393,093	187,598	158,408
EI	1,384,954	841,788	438,162	350,221
EE	703,933	492,630	251,639	218,615

II: First premolar retainer inlay- first molar retainer inlay; IE: First premolar retainer inlay- first molar retainer endocrown; EI: First premolar retainer endocrown- first molar retainer inlay; EE: First premolar retainer endocrown-first molar retainer endocrown

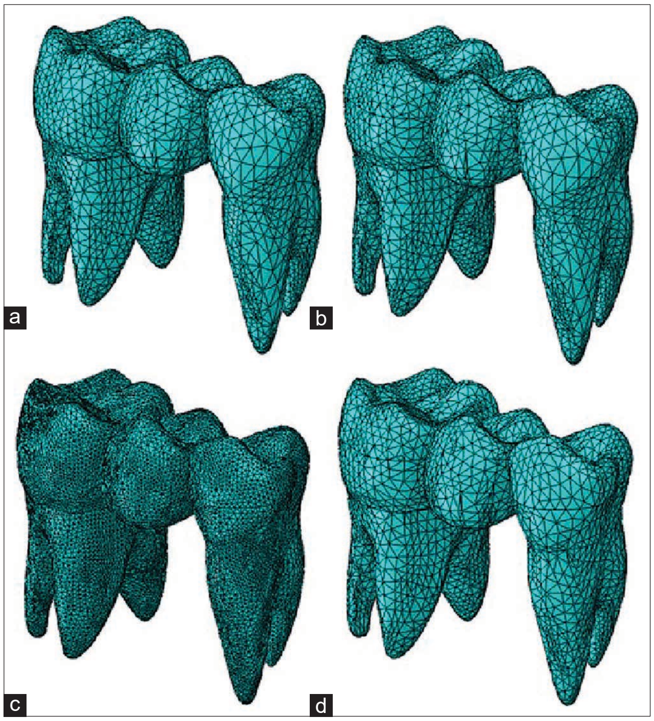

Figure 2: A tetrahedron mesh element of (a) II, (b) IE, (c) EI, and (d) EE.

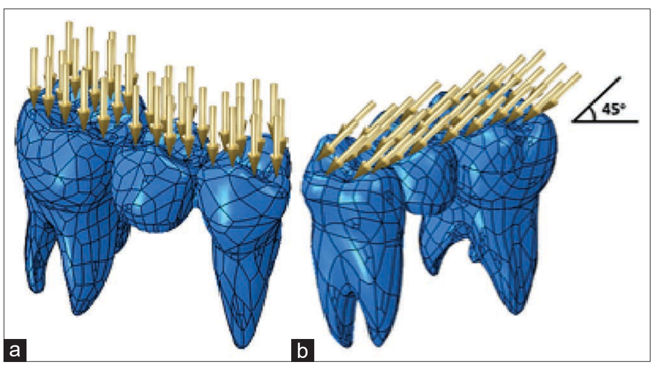

Figure 3: (a) vertical and (b) oblique loading.

a 4 mm × 3 mm connector under vertical loading. In general, EI restorations exhibited the lowest stress values across various configurations, whereas IE restorations consistently showed higher stress values. Among ceramic materials, Zr restorations exhibited higher stress values overall compared to LDS and ZLS, which demonstrated similar stress profiles. Concerning connector size, the 3 mm × 3 mm connector consistently showed higher stress compared to the 4 mm × 4 mm connector, whereas the 4 mm × 3 mm connector produced variable results dependent upon the restoration design.

Maximum principal strain values under vertical and oblique loading are also detailed in Figure 5. The lowest strain (0.5) was observed in the EI Zr restoration with a 4 mm × 4 mm connector under vertical loading. Conversely, the highest strain (4.1) was seen in the EE LDS restoration with a 4 mm × 3 mm connector size under oblique loading. The EE restoration group generally displayed higher strain values, while the EI group consistently exhibited the lowest strains. When comparing ceramic materials, LDS consistently showed higher strain values, whereas Zr exhibited the lowest. Regarding connector sizes, restorations with a 3 mm × 3 mm connector generally had higher strain values compared to the 4 mm × 4 mm connectors. Similar to stress results, the 4 mm × 3 mm connector yielded variable strain outcomes depending on restoration design.

The maximum principal stress was primarily concentrated at both connectors near the pontic region across all groups. In contrast, maximum principal strain locations varied, appearing at both connectors in II and EE groups, at the mesial connector in IE groups, and at the distal connector in EI groups [Figure 6].

DISCUSSION

Traditional full-crown preparations for FPDs involve extensive tooth structure removal, potentially compromising tooth integrity and longevity.[3] Alternatively, conservative partial ceramic preparations, such as inlays and endocrowns, preserve tooth structure and utilize adhesive retention through glass ceramics.[20] The present study aimed to evaluate the effects of restoration design, material, and connector size on stress distribution in FPDs with partial preparations. Based on the findings, the null hypothesis that restoration design, ceramic type, and connector size would not significantly affect stress distribution was rejected.

Overall, oblique loading conditions resulted in higher principal stress and strain values compared to vertical loading. The highest principal stress was predominantly observed in IE and EE designs, whereas EI configurations demonstrated the lowest stress and strain values. Among ceramic materials, Zr exhibited the highest principal stress values due to its higher elastic modulus, resulting in a greater concentration of stress compared to LDS and ZLS. Conversely, LDS consistently demonstrated higher principal strain values, reflecting its lower elastic modulus and increased deformation potential.

Most stress values observed in this study were below the reported flexural strengths for the

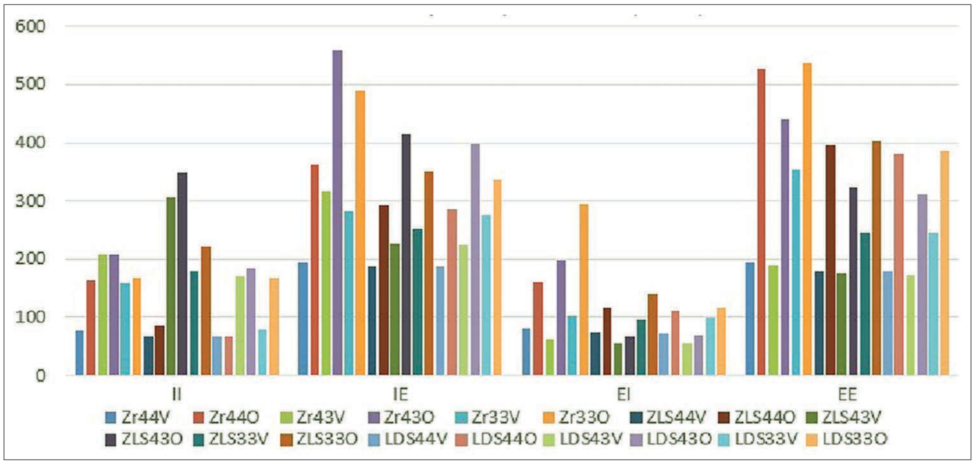

Figure 4: Maximum principal stress (MPa) of studied groups in vertical and oblique loading. II: First premolar retainer inlay-first molar retainer inlay, IE: First premolar retainer inlay-first molar retainer endocrown, EI: First premolar retainer endocrown-first molar retainer inlay, EE: First premolar retainer endocrown-first molar retainer endocrown, Zr: Zirconia, ZLS: Zirconia reinforced lithium silicate, LDS: Lithium disilicate, 44: 4 mm × 4 mm, 43: 4 mm × 3 mm, 33: 3 mm × 3 mm, V: Vertical loading, O: Oblique loading.

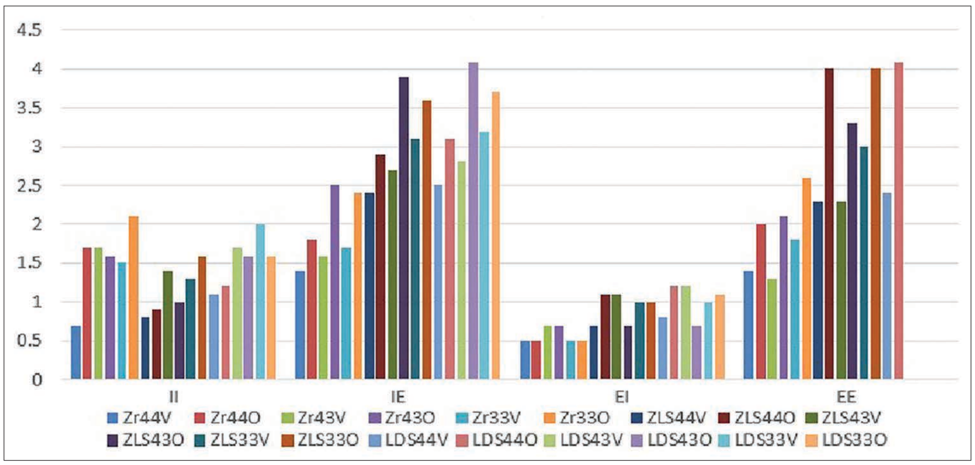

Figure 5: Maximum principal strain of the studied groups in vertical and oblique loading. II: First premolar retainer inlay-first molar retainer inlay, IE: First premolar retainer inlay-first molar retainer endocrown, EI: First premolar retainer endocrown-first molar retainer inlay, EE: First premolar retainer endocrown-first molar retainer endocrown, Zr: Zirconia, ZLS: Zirconia reinforced lithium silicate, LDS: Lithium disilicate, 44: 4 mm × 4 mm, 43: 4 mm × 3 mm, 33: 3 mm × 3 mm, V: Vertical loading, O: Oblique loading.

respective ceramics (LDS: 392.58 MPa,[21] ZLS: 383.88 MPa,[21] Zr: 1102 MPa[22]). However, under oblique loading, certain configurations exceeded the respective ceramic flexural strength thresholds, notably EE-ZLS (3 mm × 3 mm, 4 mm × 4 mm), IE-ZLS (4 mm × 3 mm), and IE-LDS (4 mm × 3 mm). Configurations approaching the ceramic threshold under oblique loading included EE-LDS (3 mm × 3 mm, 4 mm × 4 mm), IE-ZLS (3 mm × 3 mm), and II-ZLS (4 mm × 3 mm).

Regarding connector dimensions, the 4 mm × 4 mm connector consistently showed lower stress and strain values compared to the smaller 3 mm × 3 mm connector. Interestingly, the 4 mm × 3 mm connector exhibited variable results depending on restoration design, likely due to differences in cross-sectional geometry. Specifically, the oval-shaped 4 mm × 3 mm connector demonstrated favorable stress and strain distribution in endocrown-supported FPDs (EE), whereas it resulted in higher stress in inlay-supported designs (II). Osman *et al*. similarly reported that rectangular connectors exhibit better stress distribution compared to triangular connectors, suggesting tapered connectors may not be suitable for partial restorations with limited volume, such as endocrowns and onlays.[13]

Maximum stress concentrations were consistently localized at connectors, corroborating the findings from the systematic review by Castillo-Oyagüe *et al*.[3] Maximum strain locations varied depending on retainer design, occurring predominantly at connectors

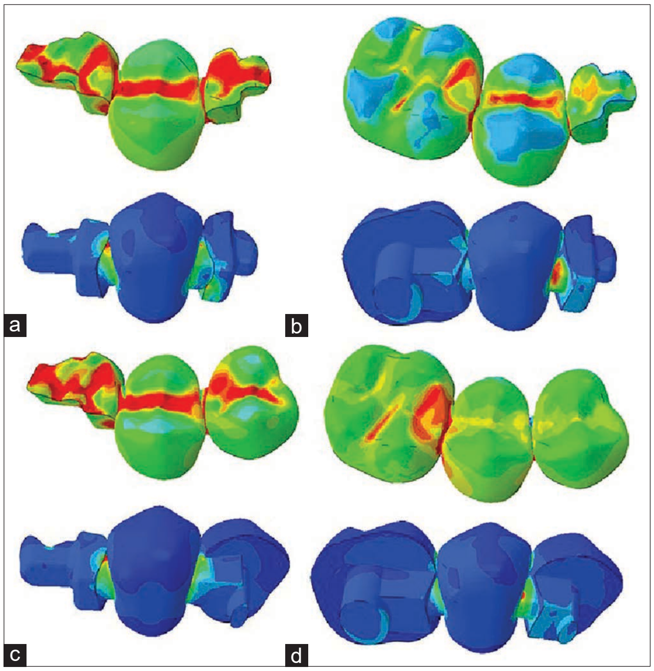

Figure 6: maximum principal stress (above) and strain (below) of four study groups (a) II, (b) IE, (c) EI, and (d) EE.

associated with retainers of smaller volume, such as inlays in mixed designs (IE and EI).

To date, no studies have directly compared partial preparation designs (endocrown and inlay combinations) as FPD retainers. Güngör *et al*. evaluated FPDs with inlay retainers made from LDS, ZLS, and Zr ceramics, concluding that Zr possessed the highest fracture strength and ZLS the lowest.[23] Consistently, Kermanshah *et al*. reported significantly lower fracture strength for ZLS ceramics in FPDs with two inlay retainers compared to Zr.[24] In agreement, the present study found higher stress values approaching ceramic thresholds for ZLS in inlay-retained designs, highlighting Zr's mechanical suitability.

Hadzhigaev *et al*. evaluated Zr FPD designs, reporting no significant differences in stress distribution between full-crown and mixed (crown-endocrown) retainer designs.[25] However, they noted increased vulnerability at the distal connectors, attributed to their horizontal oval shape – an unfavorable geometry contrary to recommended circular or vertically oval designs. Similarly, Morsi *et al*. demonstrated that FPDs combining endocrowns and full crowns resulted in variable stress distributions, suggesting that configurations with dual endocrowns may yield comparable results to conventional full-crown designs.[8] Furthermore, Tribst *et al*. affirmed the biomechanical acceptability of LDS endocrown-supported FPDs, further supporting the viability of conservative preparations in FPD designs.[6]

A notable strength of the present study is its comprehensive comparative analysis of various conservative retainer designs. Nevertheless, inherent limitations of finite element studies, including simplified assumptions of homogeneous and isotropic materials, uniform cement layers, and static loading conditions, must be acknowledged. Future studies are recommended to investigate stress distributions under dynamic loading conditions, evaluate different preparation designs in anterior regions, and include *in vitro* and clinical trials that account for bonding performance and aging effects on ceramic restorations.

CONCLUSION

Within the limitations of this FEA study, partial ceramic restorations (endocrowns and inlays) may serve as effective conservative alternatives to conventional full crowns as retainers for posterior FPDs, particularly when Zr ceramic is selected. However, caution is advised when employing partial ceramic restorations in posterior regions subjected to group-function occlusal schemes, due to the potential risk of increased stress concentrations and strain under oblique loading conditions. Concerning connector size, the 3 mm × 3 mm connector consistently showed higher stress compared to the 4 mm × 4 mm connector, while the 4 mm × 3 mm connector produced variable results dependent upon the restoration design.

Data availability statement

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

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Nil.

Conflicts of interest

The authors of this manuscript declare that they have no conflicts of interest, real or perceived, financial or non-financial in this article.

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