Loading stress distribution in posterior teeth restored by different core materials under fixed zirconia partial denture: A 3D-FEA study

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ABSTRACT: **Purpose:** To evaluate the effect of different substrate stiffness [sound dentin (SD), resin composite core (RC) or metal core (MC)] on the stress distribution of a zirconia posterior three-unit fixed partial denture (FPD). **Methods:** The abutment teeth (first molar and first premolar) were modeled, containing 1.5 mm of axial reduction, and converging axial walls. A static structural analysis was performed using a finite element method and the maximum principal stress criterion to analyze the fixed partial denture (FPD) and the cement layers of both abutment teeth. The materials were considered isotropic, linear, elastic, homogeneous and with bonded contacts. An axial load (300 N) was applied to the occlusal surface of the second premolar. **Results:** The region of the prosthetic connectors showed the highest tensile stress magnitude in the FPD structure depending on the substrate stiffness with different core materials. The highest stress peak was observed with the use of MC (116.4 MPa) compared to RC and SD. For the cement layer, RC showed the highest values in the molar abutment (14.7 MPa) and the highest values for the premolar abutment (14.4 MPa) compared to SD (14.1 and 13.4 MPa) and MC (13.8 and 13.3 MPa). Both metal core and resin composite core produced adequate stress concentration in the zirconia fixed partial denture during the load incidence. However, more flexible substrates, such as composite cores, can increase the tensile stress magnitude on the cement. (*Am J Dent* 2021;34:157-162).

CLINICAL SIGNIFICANCE: The present study shows that the choice of the cast core and metallic post by the resin composite core and fiberglass post did not improve the biomechanical behavior of the FPD. This choice must be performed based on clinical criteria (other) than mechanical.

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Introduction

Fixed partial dentures (FPDs) are an acceptable solution to replace the loss of teeth and to restore the patient's chewing, health, esthetics and function.[1] With ceramic materials in dentistry combining esthetics and resistance, metal-free rehabilitation in regions with high masticatory loads became possible.[2,3]

Yttria stabilized tetragonal zirconia (YTZP) fixed partial denture is a common prosthetic rehabilitation with excellent mechanical properties, biocompatibility and esthetics.[4] Clinically, the survival rate of this treatment was 85.0%, showing adequate longevity.[1] Even for extensive fixed partial dentures, after 5 years of follow-up, the success rate was 97.8%.[5]

However, the residual substrate available for the coronary preparation of the abutment teeth is not always suitable. In fact, teeth with extensive tissue loss, mainly after an endodontic treatment, requires an intraradicular post placement and an ideal core build-up before the final prosthetic restoration.[6]

Metallic cores have been used for a long time as retainers to support fixed restorations.[7] Recently, they have been gradually replaced by polymeric based materials such as resin composite cores with high dentin adhesion and esthetic properties;[8] fiberglass posts with superior mechanical behavior are also adhesively incorporated to the core materials in endodontically treated teeth to rehabilitate the tooth structure.[9,10] In this context, FPDs can be cemented to different types of substrates according to the clinical situation. The role of metallic core, resin composite core or sound dentin and their mechanical behavior have not yet been investigated.

To understand the influence that the substrate (sound dentin, resin composite core and metallic core) have on the stress distribution in a zirconia FPD, an in-silico study was carried out using the finite element analysis (FEA). In dentistry, FEA can be applied to analyze the stress and strain using boundary geometries to study dental rehabilitation,[11-14] as well as in other dental areas.[10,15] FEA is used to investigate the material's behavior under strength, stiffness and fatigue testing applications.[16]

This study evaluated the influence of different substrates on the stress distribution of a zirconia FPD using the 3D FEA. The null hypothesis was that there would be no difference in the stress distribution in the FPD regardless of the substrate: sound dentin, resin composite core or metallic core.

Materials and Methods

For the present study, the 3D geometries were modeled using a computer aided design (CAD) software (Rhinoceros 4.0[a]). A 3D model of a partial right jaw from São Paulo State University database (UNESP - ICT São José dos Campos) was exported to the CAD software. The 3D model with the lower first molar, second premolar and first premolar was created as a volumetric model. The command "reduce mesh" available with a plugin in CAD software was used with 50% relevance, allowing a smoother structure with all normal face oriented in the same direction; then, NURBS surfaces were created from the mesh. The 3D volumetric model of a FPD with first molar and first premolar was developed based on the surface created by the curve network generated automatically. The central pontic was created in the same way, however, without root.[17] The connector presented rounded shape and area of 4.2 mm^2 for both abutment teeth.

After the modelling process, the dental crown preparation was performed. For both abutments, the preparation had rounded corners, 6° degree of axial walls and 1.5 mm of occlusal reduction with the shoulder finishing line.[10] The cement layer was modeled with 100 µm thickness between the prosthesis intaglio surface and adhesive surface of the teeth. For an isotropic bone simulation,[18] a polyurethane block (25 × 10 × 10 mm) was created to embed the specimens. Figure 1 summarizes the modeled structures and groups distribution according to the simulated substrates.

Each model was exported in STEP format to the analysis software (ANSYS[b] 17.2) and the meshing was performed using tetrahedral elements. The materials were considered isotropic, homogeneous, and linearly elastic. The properties required for the mechanical analysis are summarized in Table 1.[19-25] For the meshing, the convergence test was based on the number of nodes (370,844) and elements (197,426) obtained with 10% relevance. The fixed support was defined on the polyurethane bottom surface and the axial load of 300 N[18] was applied at the center of the pontic using the force vector, applied in occlusal areas similar to ideal occlusal contact points (Fig. 2). The maximum principal stress was evaluated through colorimetric graphs and the stress peaks were recorded for quantitative comparison between the models.

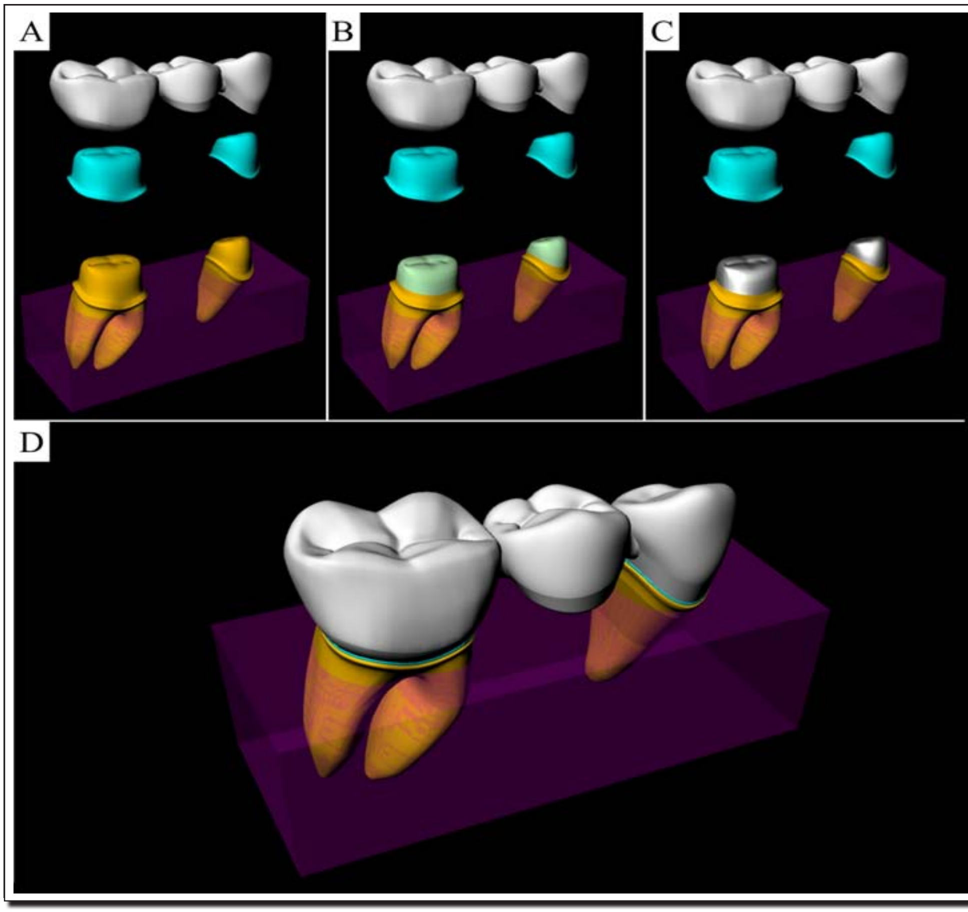

Fig. 1. Three dimensional models used in the present study. **A.** Sound dentin abutment teeth, **B.** Resin composite core abutment, and **C.** Metal core abutment. **D**. Model with the prosthesis in position.

Results

The maximum principal stress distribution in the FPDs and cement layers are displayed in Figs. 3 and 4.

Figure 3 shows the stress concentration in the FPD from an occlusal view and in a section plane. Regarding the FPD's behavior, it was noticed that the prosthetic connector region concentrated higher stress magnitude regardless of the substrate material. The molar's connector showed a higher stress concentration than the premolar's connector regardless of the substrate material. However, the lower the elastic modulus used in the substrate the lower the stress concentration in the connector's region. A high stress magnitude at the distal region margin of the molar tooth was evident in the colorimetric maps. However, the values ranged from 13.8-14.7 MPa between the models. The stress data is summarized in Table 2.

The stress maps for the cement layer were summarized in Fig. 4. Regardless of the substrate stiffness used as core material, the stress maps between the models were very similar in terms of stress pattern and distribution. However, the model with resin composite as core material showed the highest stress concentration (14.7 MPa) in the intaglio surface of the resin cement, with a visible difference in the mesial portion of the cement at the premolar abutment.

Table 1. Mechanical properties of the materials used in the finite element analysis.

Materials/substrate	Elastic modulus (GPa)	Poisson ratio
Dentin	18.6	0.30
Polyurethane	3.6	0.30
Resin cement	10	0.30
Composite core	12	0.25
Metal core (Ag-Sn alloy)	60	0.23
Zirconia	200	0.30

Discussion

This study evaluated the influence of different substrates on the stress distribution in a zirconia FPD and on the cement layer, using finite element analysis. According to the results, the null hypothesis was rejected since the different substrate mechanical properties revealed different behavior and stress magnitudes in the models evaluated. Regarding the cement layer, the core in resin composite showed the highest stress concentration (Fig. 4).

In dental practice, restorations luted to dental tissue can fail in different ways, such as: fracture (subcritical growth cracks, chipping), debonding or secondary caries.[26] In the literature, reports show failures in the region of the FPDs connectors, which can lead to a catastrophic fracture of the restoration and compromises the dental treatment.[27] Typically, these failures are associated with extensive rehabilitation or large edentulous spaces.[28] In vitro studies[29,30] demonstrated that the fracture begins in the connector area.

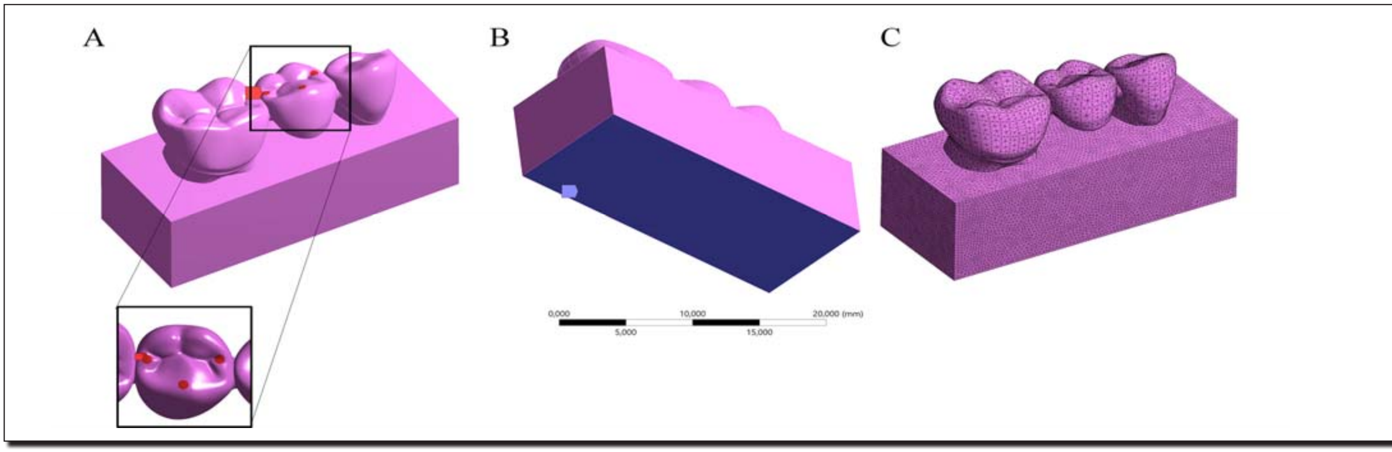

Fig. 2. Boundary conditions. **A.** Loading application, **B.** Fixed support, and **C.** Meshing division.

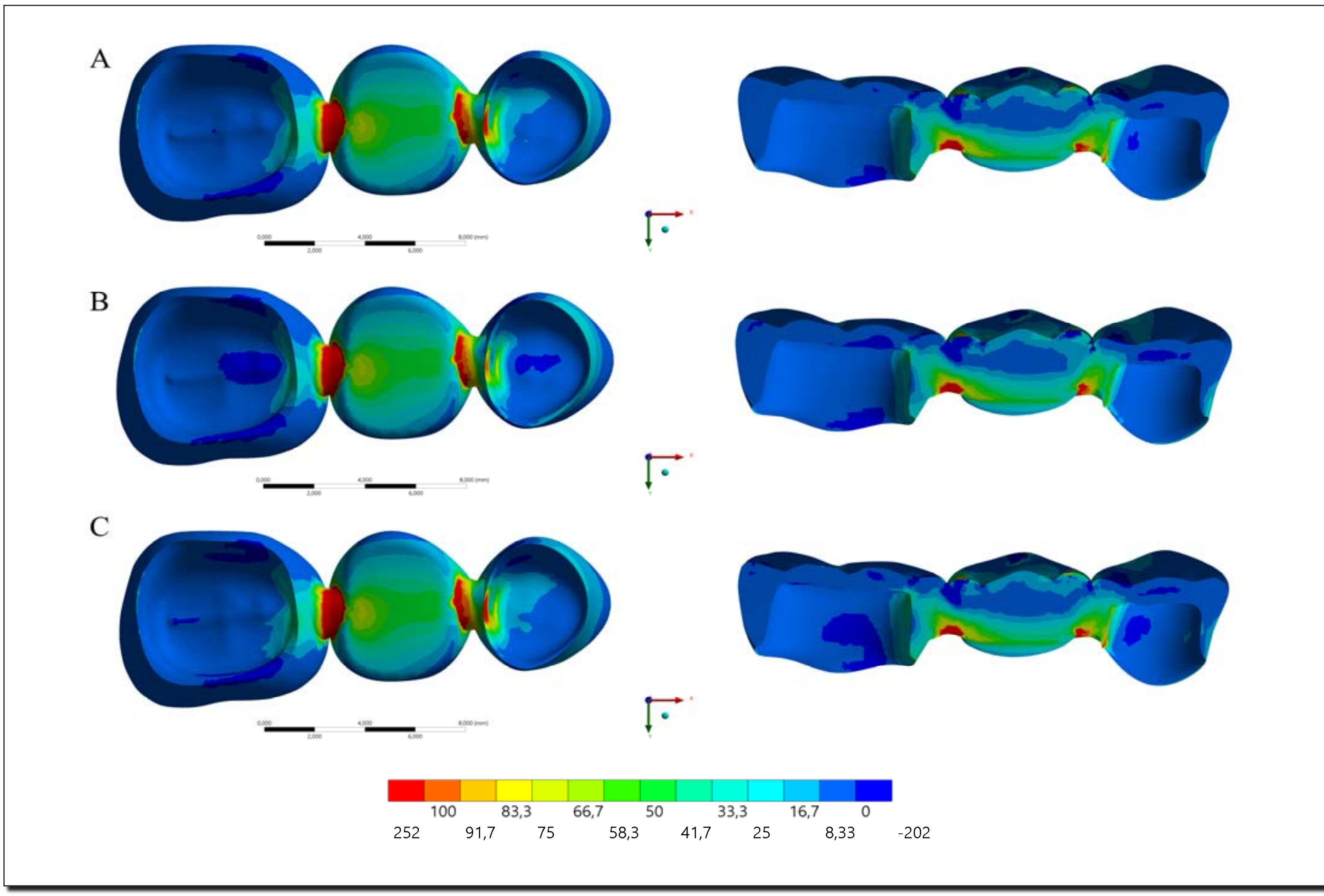

Fig. 3. Maximum principal stress distribution (MPa) for each analyzed FPD according to different substrate. **A.** Sound dentin abutment teeth, **B.** Composite core abutment, and **C.** Metal core abutment.

The present study corroborated these findings, considering that the fracture pattern was also determined by the stress distribution in this structure. Understanding the restoration fracture mechanics is important because its longevity is directly associated with the stress distribution.

Zirconia has gained popularity in dentistry due to its great biocompatibility, good esthetic characteristics and because it has high mechanical properties such as fracture toughness and flexural strength. Compared to the other available ceramics, zirconia can be applied in regions with high occlusal load.[31] This material can approach the nuance of color of the teeth compared to a metal framework, can replace a metal framework in FPDs and can guarantee esthetics.[32] The mathematical simulation of the present study evaluated a FPD in zirconia, which is a material widely used for indirect restorations and indicated to rehabilitate the posterior region.

In addition, zirconia is a brittle material able to support compression stresses much better than tensile stresses due to the presence of inherent flaws in their crystalline structure.[29] Thus, the use of the maximum principal stress criterion is justified, since the tensile stresses are evident in the critical areas of the prosthetic structure. In addition to the stress magnitude,

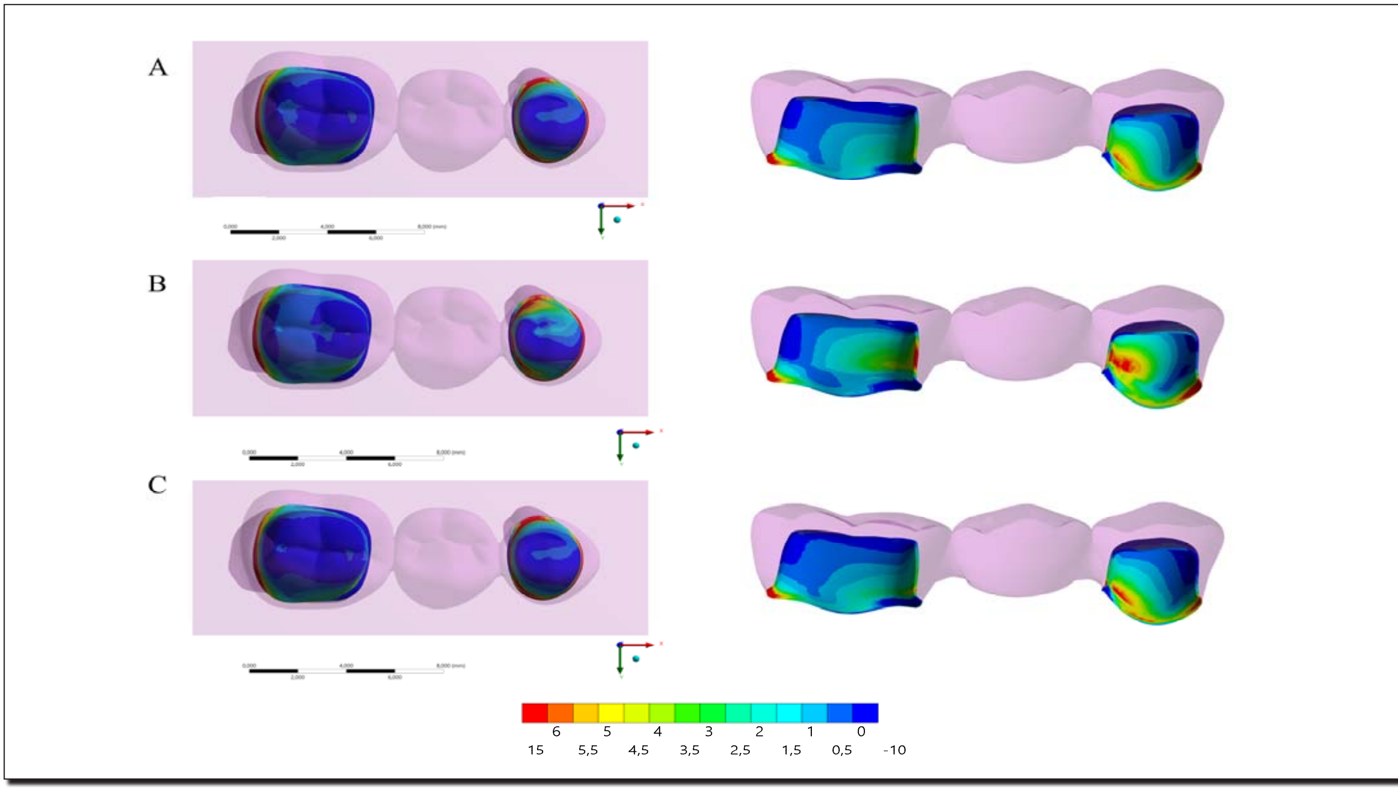

Fig. 4. Maximum principal stress distribution (MPa) for each analyzed cement layers according to different substrate. **A.** Sound dentin abutment teeth, **B.** Composite core abutment, and **C.** Metal core abutment.

Table 2. Stress peaks (MPa) generated in the FPD and cement layers for each abutment according to the evaluated substrate materials.

	Prostheses		Cement	
Materials/substrate	Molar connector	Premolar connector	Molar abutment	Premolar abutment
Sound dentin	113.1	112.5	14.1	13.4
Resin composite core	111.6	111.4	14.7	14.4
Metal core	116.4	115.5	13.8	13.3

several factors influence the fracture resistance, such as the elastic modulus of the supporting structures, cement properties, surface roughness and the substrate that will receive the restoration.[33] In a complementary way, the results found in the present study demonstrate that the rigidity of the prosthetic abutment can affect the dissipation of the masticatory loading stresses.

It is well known that dental anatomy influences the dental preparation for prosthetic purpose and its subsequent restoration.[3] Dental preparation for a molar total crown provides a more stable and retentive support for the restoration than a premolar tooth due to its anatomy and greater volume. In this sense, it is possible to justify the higher stress values generated in the resin cement layer in the premolar region.

As demonstrated in the present study, in a posterior FPD, the stress concentration occurs in the connector with the pontic. In a previous FEA study,[17] this same pattern was observed for different substrate materials. This finding also confirms the in vitro and in silico study[34] in which the resistance of a FPD of three elements made in translucent zirconia was estimated and the failure in the connector region occurred the most.

In the resin composite FPD, the same failure pattern in the connector region was reported,[35] located between the first and second premolars. The authors justified this behavior because the axial load stress distribution was concentrated in the area of the connectors and not in the adhesive interface between the prosthesis and the abutment tooth.

Different studies have evaluated the fracture resistance of ceramic crowns using metal, acrylic resin and dentin as support materials.[36,37] It is known that increasing the abutment elastic modulus also increases the fracture resistance for ceramic posterior single crowns.[38] This mechanical behavior is justified because for more rigid substrates a greater load will be necessary to deform the restorative material. For all models, the results showed that increasing the abutment elastic modulus, the FPD fracture risk increases since the magnitude of the stresses generated would be higher.

Considering the substrate, fiberglass posts with resin composite cores are an alternative to restore areas with high esthetic demand.[39] However, when exposed to cyclic loading, they will show debonding between the post and core interface, losing adhesion and increasing the chance of failure.[40] It is known that ceramic restorations' fracture and fatigue resistance is increased when cemented with an adhesive material on a suitable substrate.[41] In metal cores this does not occur, since these materials have low adhesive characteristics.

Posts are normally used to provide retention to the core in endodontically treated teeth with extensive loss of coronal and intracanal structure.[42] Occasionally, the post and core structure that receives a prosthetic restoration can present failures due to debonding and root fractures.[43,44] Considered as a complex structure (core/cement/prosthesis), it may fail in the weakest component: the resin cement. Debonding in this region can lead to changes in the restoration's stress distribution.[26]

Cements play a crucial role in the longevity of adhesive prosthetic rehabilitations.[45] Although conventional cements are widely used because they offer a simple technique and proven efficacy, resin-based cements are considered more effective in promoting a longevity of the core adhesion. Since resin cements have higher clinical reliability and an efficient bond strength,[46-48] higher root fracture resistance can be achieved with the use of it.[49]

Reduced root fracture possibility was attributed to the composite and the fiberglass post elastic modulus because they mechanically behave more closely to dentin compared to the cast alloys.[49,50] However, another study[51] showed that a metal restoration with high modulus is able to absorb a large amount of stress generated in the cemented tooth structure, resulting in less stress dissipation in the root dentin.

Limitations of this study were that it did not evaluate the optical properties of the substrate,[52] did not consider fatigue effects, assumed homogeneous isotropic and linearly elastic materials in the biomechanical and interface FEA analysis.[53-59] Therefore, further studies may evaluate these issues.

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