



Effect of Thickness of Various Restorative Materials and Hybrid Layer on Stress Distribution of Direct Cervical Restorations of Teeth Using a Three Dimensional Structural Finite Element Analysis

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Abstract

Challenging clinical conditions such as bonded restorations can be effectively simulated using finite element analysis and the nature of stress and deformation that leads to the failure of restoration can be analyzed. Glass ionomer cement (GIC) and composite resin (a combination-bilayered restoration with a hybrid layer in between) are widely used restorative materials for cervical cavities. The aim of the study is to evaluate the effect of thickness of GIC and composite resin on stress distribution on cervical restorations. A finite element model was constructed and imported to three-dimensional (3D) image analysis. The model was layered with enamel, dentin and cementum and the cavity of specific dimension was prepared. The cavity was restored with solid blocks of restorative materials of varying thickness. The force was applied on the cusp with fixed support at the cervical area of the tooth and the analysis was carried out in ANSYS Workbench Version 19.0. Ovoid shaped cavity with 6 μm thick hybrid layer showed least stress value of 0.574 Mpa amongst all the groups. It is concluded that a thicker hybrid layer reduces the stress within the restoration and a thicker GIC with hybrid layer under composite resin is a better option for a bi-layered restoration in the cervical cavity.

Keywords: Cervical lesions; Dentistry; Dental materials; Finite element analysis; Resin Composite.

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1. Introduction

Restoration of a tooth is a meticulous task as it not only involves the structural but also functional integrity of the tooth. Non-cariou cervical lesions (NCCLs) have a multifactorial origin, with the proposed predisposing factors being stress (abfraction), mechanical wear (from toothbrush/dentifrice

abrasion) and bio corrosion (chemical degradation) thereby leaving the cervical dentin exposed.^[1] The lack of retention in the cervical area specially, with the cavity margins on dentin and non-availability of enamel, makes it challenging for restoration.^[2] The high organic content of dentin, along with its tubular structure and outward flow of fluid, make dentin bonding difficult to attain.^[3] Moreover, increased incidence of sclerotic dentin in the cervical area, affects the adhesion between dentin and resin. Materials such as glass ionomer cement (GIC), resin modified glass ionomer cement (RMGIC) bond chemically with the tooth structure and have shown promising clinical outcomes.^[4,5] However, both these materials have inferior esthetic outcomes when compared with the composite resin and cannot be used primarily in the esthetic zone.^[6,7] In adhesive dentistry, the properties of GICs and composite resins were utilized and ‘sandwich restoration/bilayer lamination technique’ was proposed where, GIC is first compacted on the open dentinal surface followed by etching, bonding and restoring the cavity using composite resin.^[8,9] Due to advantages such as fluoride release, increased

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compressive strength and thermal insulation provided by GIC under the composite resin, it has shown promising results.^[10] Etch and rinse technique of bonding, comprises of use of water on the surface of freshly set GIC leading to dissolution of the surface structure.^[11] Therefore, self-etching technique of bonding has evolved over the recent years and has shown better bond strength between GIC and composite resin.^[12] Bond strengths alone are inadequate indicators of bonding efficacy and that they may be misleading for evaluating the efficacy of bonding restorative systems.^[13] There are no previous research carried on the influence of thickness of each of the material (GIC and composite resin) and the stress distribution within the restoration that can affect the bonding in NCCLs. The finite element assessment is an emerging technology which is widely used for modeling and simulating the circumstances of dental treatment, the procedures engaged and the impacts of post-treatment procedures.^[14] Therefore, this study was stemmed to evaluate the effect of thickness of various restorative materials on stress distribution of direct cervical restorations using a three-dimensional structural finite element analysis. It was hypothesized that there is no difference in the thickness of material and stress distribution.

2. Materials and methods

2.1 FE model generation

A three dimensional (3D) mandibular model was created from the digital imaging and communications in medicine (DICOM) images obtained from cone beam computed tomography (CBCT) of an extracted premolar tooth. The generated model was then imported to a 3D modelling tool “Spaceclaim” for further modifications. The imported file was in initial graphics exchange specification (IGES) format. The model contained

all the layers of the tooth; enamel dentin and cementum. Spaceclaim was utilized to refine the layout of internal contours, edges and occlusal anatomy. The finite element (FE) analysis was carried out in ANSYS Workbench Version 19.0 (Swanson ANSYS, Houston, Pennsylvania).

2.2 Material properties

Materials that were considered for the analysis were assumed to be isotropic, homogenous and linearly elastic. GIC, hybrid layer, composite resin were used as the layers of restorative material for the analysis. Linear elastic constants (Young’s modulus and Poisson’s ratio) and density of each material were specified for structural analysis are shown in Table 1.

Table 1. Properties of materials considered in the study.

Properties	Glass ionomer cement	Hybrid layer	Composite resin
Young’s Modulus	10.8 GPa	15.5 GPa	15 GPa
Poisson’s Ratio	0.3	0.28	0.24

2.3 Preparation of the cavity

A prismatic cavity was created across the mesio-distal-occlusal wall with total depth of 3 mm. The cavity so formed was symmetric about cemento enamel junction (CEJ). Two shapes of cavity were considered for the analysis: oval and trapezium. The cavity was restored with three materials; GIC, hybrid layer and composite resin (Fig. 1a and Fig. 1b). Basically, the cavity was divided into two solids; Solid-1 and Solid-2 (Fig. 1c and Fig. 1d). The Solid-1 was at the rear part of the cavity and was made of GIC. Solid-2 was glued above

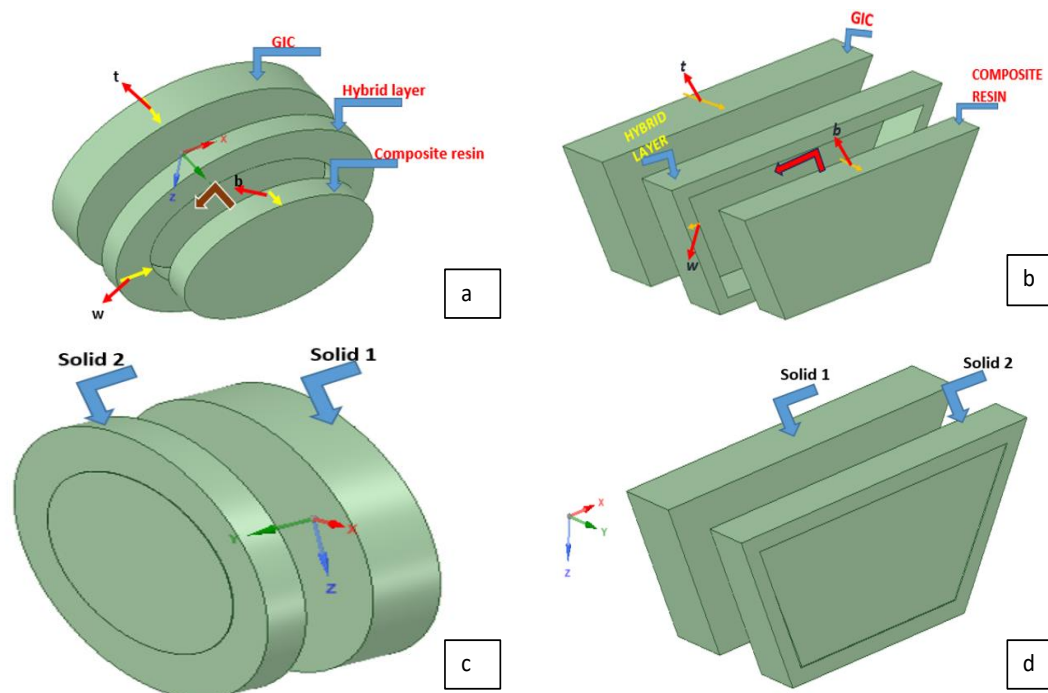


Fig. 1 Preparation of the cavity (a) layering of restorative material for ovoid cavity, (b) layering of restorative material for trapezoid cavity, (c) solids 1 and 2 for ovoid cavity, (d) Solid 1 and 2 for trapezoid cavity.

the Solid-1 and was made of Hybrid layer and Composite resin. The Solid-2 was made in such a way that composite resin was at the core and hybrid layer was at the periphery. Thickness of GIC-“t”, Thickness of composite resin-“b” and Thickness of hybrid layer-“w” was varied in order to study their response towards static loading conditions. The thickness of restorative material blocks of the cavity are listed in Table 2.

Table 2. Division of groups according to the thickness of restorative materials.

Groups	Thickness of layers of Restorative Materials		
	Glass Ionomer Cement (mm)	Hybrid layer (Micron meters)	Composite resin (mm)
Group 1	1	3	2
Group 2	2	3	1
Group 3	1.5	3	1.5
Group 4	1.5	6	1.5
Group 5	1	6	2
Group 6	2	6	1

2.4 Meshing

The CAD model with restored cavity was exported to ANSYS Workbench for meshing. Mesh was generated using tetrahedral elements where mesh density was kept medium outside the cavity region, while the finer mesh density was adopted at cavity region. Body sizing feature was used in order to reduce the element size to 0.5 mm.^[15] Refinement of mesh was carried out to improve element quality index. As a result, the model contained 65,037 nodes and 42,506 elements.

3. Boundary conditions

The meshed model was subjected to static loading of 100N (Fig. 2a) as a force load perpendicular to the lingual plane of the buccal cusp on the occlusal surface (normal load) to simulate the chewing force (Fig. 2b). The portion of cementum that is supposed to be embedded within the gums was fixed (Fig. 2c). The equation (1) and equation (2) pertain to boundary conditions considered in the present study, (a) For the fixed (a part of the cementite)

$$d_x=d_y=d_z=R_x=R_y=R_z=0 \tag{1}$$

All the degrees of freedom are constrained (d – translational degrees of freedom in global X, Y, Z directions and R- rotational degrees of freedom in global X, Y, Z direction)

(b) Load Application

$$F= 0 e_1 + 0 e_2 - 100 e_3 \text{ Newtons} \tag{2}$$

where e₁, e₂, e₃ are three mutually perpendicular unit vectors and e₃ is the outward normal to the cusp surface.

Von Mises stress and total deformation of the cavity was calculated to determine the capability of these layers to withstand chewing force/occlusal loading.

4. Results

In the present study it is observed that even though the same materials were used for restoration of trapezoid and ovoid cavity, a proper trend was not obtained when the results of both the shapes and thickness of the materials were combined.

The least von misses stress for ovoid shaped cavity, was shown by the group 6 (2 mm GIC, 6 μm adhesive layer and 1 mm composite layer) and the highest was shown by group 3 (1.5 mm GIC, 3 μm adhesive layer and 1.5 mm composite layer) (Fig. 3, Table 3). Whereas, in the trapezoid shaped cavity, highest stress is observed in group 2 (2 mm GIC, 3 μm adhesive layer and 1 mm composite layer) and least stress in group 5 (1 mm GIC, 6 μm adhesive layer and 2 mm composite layer) (Fig. 4, Table 3). It is observed that maximum deformation occurs at the upper right end of the cavity (Fig. 5). Deformation in the bottom half of the cavity is zero since it is subjected to fixed support constraint.

5. Discussion

Stress distribution of the various transient thermo-coupled structural finite element analysis is an appropriate method to monitor the biological systems and helps to understand the complex stress distributions within the cavity. The raw data obtained from the CBCT scanner was preprocessed and 3D reconstruction of obtained images was done using open

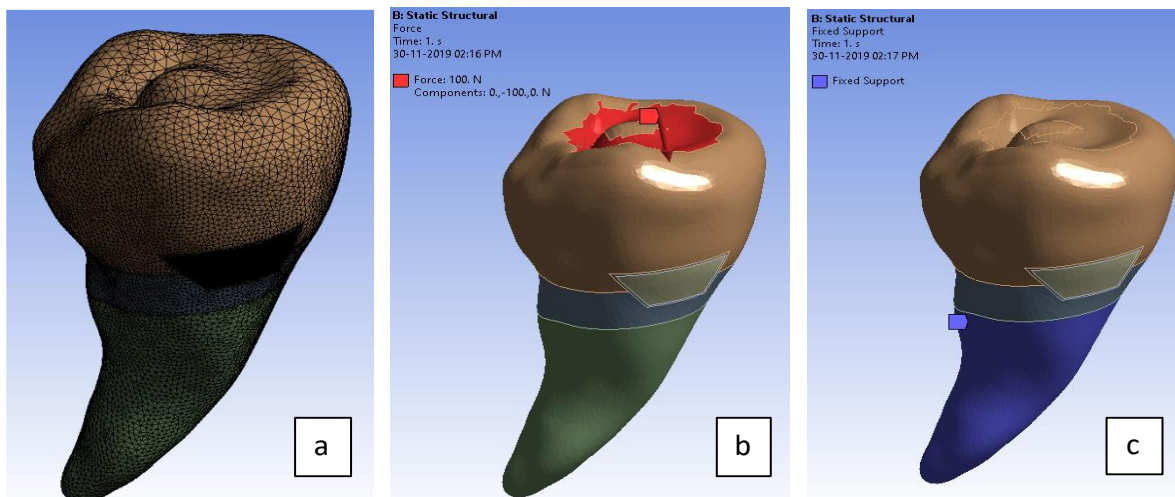


Fig. 2 Boundary conditions (a) meshed model, (b) force application, (c) fixed support.

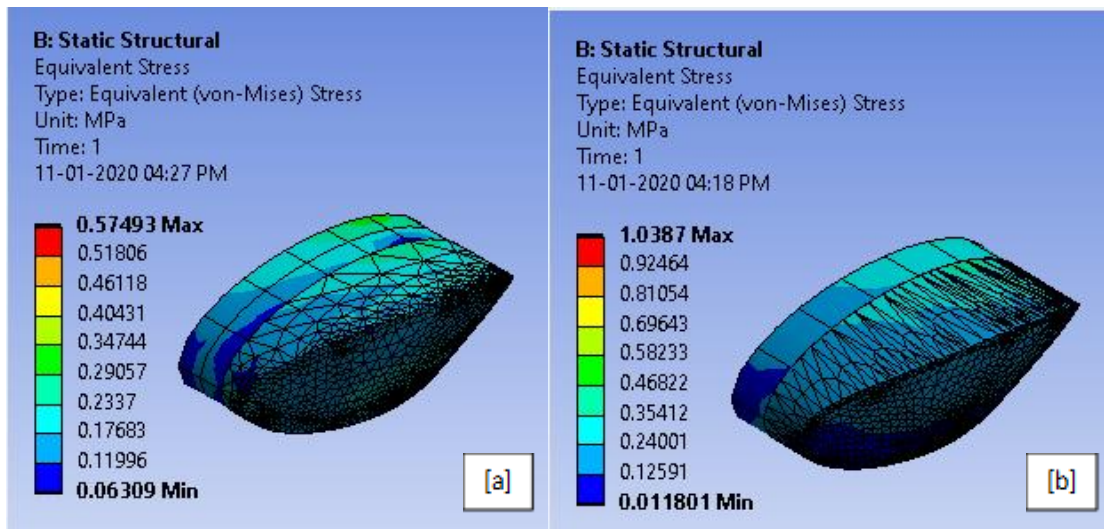


Fig. 3 Stress on Oval cavity under static loading (a) Least stress value (b) Highest stress value.

Table 3. Von Mises stress values for Ovoid and Trapezoid Category groups.

Ovoid & Trapezoid Cavity Groups	Least Von Mises stress (MPa) (Ovoid)	Least Von Mises stress (MPa) (Trapezoid)
Group 1	0.68	0.97
Group 2	1.37	0.69
Group 3	1.1	1.03
Group 4	0.89	0.74
Group 5	0.59	0.73
Group 6	0.57	0.57

source cone-beam reconstructions (OSCaR). An imported geometry may include very sharp edges or other features which may not imitate a general anatomy of the tooth. Therefore it was necessary to use Repair and prepare tool in Spaceclaim to refine the geometry.

It is found that the retention rate of sandwich restorations is more than direct composite resin restoration in NCCLs.^[16] However, the thickness of each of the restorative material within the bilayer restoration is not mentioned. It is found that the thickness of the base is an important factor that affected

the fracture strength of the amalgam.^[17] Generally, the thickness of the pulp protecting agent depends on the remaining dentin thickness (RDT). A base of thickness 0.5-0.75 mm is given on the pulpal floor and axial wall in cases where the RDT is 0.25 mm - 0.5 mm.^[18] Therefore, the thickness of the GIC base material below the composite resin was minimum 1 mm. Different groups with varying thickness of the materials were designed within the cavity to best select the suitable thickness combinations of the materials.

In the present study, restoration of the ovoid and trapezoid shaped cavities at body temperature showed comparable stress values. This further justifies that transfer of load between the layers is largely governed by the cavity shape. In case of ovoid shape, the contact established between the layers is good when compared with trapezoid cavity, which is responsible for better transfer of load from one layer to other. In a similar study by the same authors, it was found that, ovoid shape of the cavity in cervical area showed lesser stress concentration and deformation than trapezoid cavity while restored with GIC.^[15] This could be due to the increased stress concentration in cavity shapes having sharper edges, such as in trapezoid cavity.^[19]

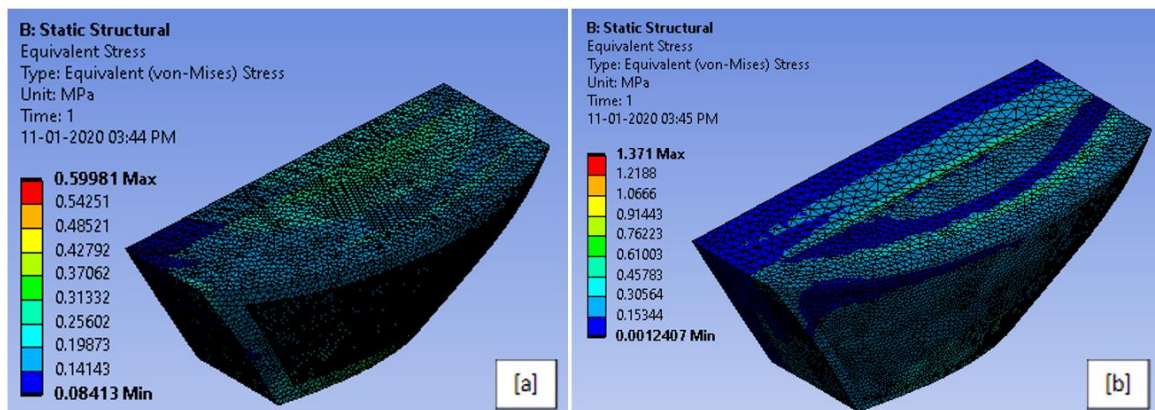


Fig. 4 Stress on trapezoid cavity under static loading: (a) Least stress value (b) Highest stress value.

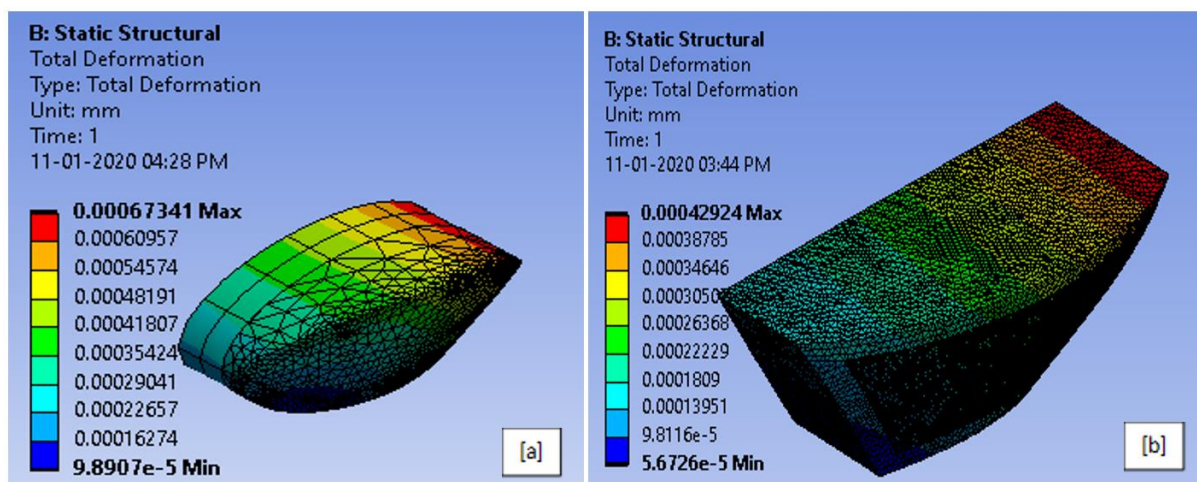


Fig. 5 Total deformation (a) Ovoid cavity, (b) Trapezoidal cavity.

It is known that the presence of hybrid layer reduces the stress distribution as it acts as a buffer due to its lower Young's modulus of elasticity.^[20] Various studies have evaluated the length, thickness and pattern of the hybrid layer that forms when the resin interlocks and bonds to the dentin.^[21,22] A thicker hybrid layer is observed when the etch and rinse technique was employed.^[21] Therefore, the thickness of adhesive layer (hybrid layer) for etch and rinse was kept at 6 μm and for self-etch it was 3 μm .^[22]

In both the shapes considered in the current study, it is observed that increase in the thickness of hybrid layer, has shown less stress values. Load is applied perpendicular to the cusp and the bottom part of the cavity is fixed. Since the tooth is not straight the eccentricity of the load induces moment that results in bending stress in addition to direct normal stresses. These stresses are responsible for the strain observed. As all three materials are bonded together, due to compatibility constrain they will have same elongation.

Young's modulus/elastic modulus defines the stiffness of any material. Higher the elastic modulus, stiffer is the material. Therefore, a material having higher elastic modulus will require higher load for same amount of deformation. Out of all the materials used for the analysis, GIC has the lowest Young's modulus. As mentioned earlier, the better transfer of load in ovoid cavity meant that the applied load was effectively transferred to cavity resulting in higher deformation when compared with trapezoid cavity. It is observed that maximum deformation occurs at the upper right end of the cavity (Fig. 5a and Fig. 5b). Deformation in the bottom half of the cavity is zero since it is subjected to fixed support constraint.

In the present study the deformation encountered in both the shapes are very negligible, hence it wouldn't be appropriate to compare entirely based on deformation. Analyzing, the region of maximum stress it is observed that the higher stress values are encountered at the interface between the hybrid layer-GIC (Fig. 3 and Fig. 4). Therefore, it becomes necessary to achieve good adhesion between the two layers in order to withstand the applied load.

The results are in accordance with a similar Finite Element

Method study which suggests that the presence of a hybrid layer altered the shear stress distribution.^[21] Further, increasing the thickness of hybrid layer, reduces the intensity of shear stress formed under occlusal loading in wedge-shaped cervical lesion restored with composite resin.^[21] It is also speculated that the hybrid layer might play a role in absorbing stress in the dentin bonding procedure.^[13] It has been suggested that to use self-etch adhesives to bond GIC and composite, as the use of phosphoric acid leads to higher cation neutralization and forms fragile salts.^[23] Forming a thick hybrid layer for Class V restorations is necessary to prevent stress from forming in the bonding layer after polymerization shrinkage.^[24]

In the present study, it was observed that for oval shaped cavities, 2 mm thickness of GIC and 1 mm thickness of composite resin showed lesser stress values for both the thickness of hybrid layer. Whereas for the trapezoid cavity 1mm thickness of GIC and 2 mm thickness of composite resin showed lesser stress values. An in vitro study by Gopikrishna *et al.*^[26] evaluated the shear bond strength of resin composite bonded to GIC using different adhesives, 6 mm thickness of GIC was used under 3 mm of composite resin and have found that self-etch primer over unset GIC has comparable bond strength to total etch after the complete set of GIC. The thickness of GIC in the sandwich restoration plays an important role as thinner layers have shown cohesive failures under composite resin.

These results can be clinically applied and understood that increased thickness of GIC under composite resin restoration in cervical areas could be a good option for ovoid shaped cavities. However, etching unset GIC in the same clinical appointment may have deleterious effect on the properties of the material.^[11,27,28] Scheduling another appointment for etch and rinse technique and layering with composite resin is not a good practice. Therefore, self-etch technique of adhesion is recommended as the next best option than total etch technique.^[9,25] The null hypothesis was rejected as there is a difference in stress distribution when different thickness of materials were used. Further studies are required to assess the stresses and deformation of sandwich restoration between

RMGIC and composite resin as there is a better chemical bonding between the two. Composite resins of different filler contents may influence the modulus of elasticity and thereby the stress and deformation of the restoration.^[29,30]

6. Conclusion

The oval shaped cavity showed the least von mises stress as compared to trapezoidal cavity in varying thickness of restorative materials in cervical area. The increased hybrid layer thickness with thicker GIC base under composite resin restoration in oval shaped cavities show lesser von mises stress values of bilayer restoration in cervical areas. The clinical implications are: In a bilayer restoration, thicker GIC base with etch and rinse technique of bonding system is better option under composite resin in cervical cavities.

Conflict of interest

There are no conflicts to declare.

Supporting information

Not applicable.

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