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Original Article

# The effect of the material used and the pulp chamber extension depth on stress distribution of endocrowns: A three-dimensional finite element analysis

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## Abstract

**Aim:** The aim of this study was to examine the effects of materials used and the depth of extension into the pulp chamber on stress distribution in mandibular molar endodontically treated teeth with endocrown restoration using three-dimensional (3D) finite element analysis (FEA).
**Methodology:** Three-dimensional finite element analysis models were obtained at two different pulp chamber extension depths by taking a tomography of a root canal-treated mandibular molar tooth extracted for periodontal reasons: 2.5 mm (Model A) and 3.5 mm (Model B). Models were divided into the following three groups according to material type used: Vita Enamic (VE), Lava Ultimate (LU), and IPS e.max CAD (EMX). The aforementioned model groups were further divided into the following two subgroups according to the types of cement used: NX3 and MaxCem Elite Chroma (MX). Maximum principal stress (MPa) values under 600 N vertical load were investigated to evaluate the effect of restoration design, material type, and cements used on stress distribution.
**Results:** The maximum stress on the restoration was observed in the EMX material type (13.000 MPa) in the MX cement group in Model A, while the lowest was observed in the LU material (5.932 MPa) in the NX3 cement group in Model A. The areas of highest stress for both Models A and B were observed in the restoration areas corresponding to the enamel margins.
**Conclusion:** Materials with a higher elastic modulus show a higher stress area on the restoration surface, while the stress values they transmit are lower. Materials with the elastic modulus close to dentin have more homogeneous stress distributions within the restoration.

**Keywords:** Finite element analysis, endocrown, stress distribution, endodontically treated teeth, CAD-CAM

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## Introduction

The restoration of endodontically treated teeth is still considered a clinical challenge due to the increased risk of biomechanical failure caused by excessive tissue loss. Endodontically treated teeth are susceptible to fracture as the moisture content in the dentin decreases (1). Teeth restored with the traditional post and core system are more prone to root fracture during the preparation of the post space. For this reason, endocrown restorations uniting the pulp cavity and crown have gained popularity. In addition, the increase in adhesive dentistry applications and developments in minimally invasive approaches may also be the reasons for the rise in the frequency of endocrown restorations (2). Full glass ceramic crown restoration was recommended in 1999 by Bindl and Mörmann as a substitute to the full post-and-core-supported crown; "endocrown" is a one-piece ceramic material. This endocrown would be fixed to the internal walls of the pulp chamber and on the cavity margins to improve macromechanical retention and the use of adhesive cementation would also improve microretention (3). Endocrown, a monolithic restoration type, enables micro- and macromechanical retention by deriving support from the pulp chamber and cavity walls. Clinical studies report that dental endocrowns have a success rate of 94–100%. One of its other advantages is that it can be placed in a single session (4). Short clinical crown length is frequent in endodontically treated teeth, and it is challenging to create an adequate retaining area to achieve good retention and stability in full crown preparation (5). A clinical study reported that no significant difference was found in the survival of endodontically treated teeth with endocrown restorations in the posterior region and teeth treated with traditional post core systems. This result suggests that endocrown restorations may be a reliable alternative to the traditional method (6).

CAD-CAM ceramic materials have been introduced with improved mechanical properties and excellent optical characteristics. Ceramic restorations have gained popularity due to their aesthetic features, biocompatibility, and durability. However, the potential for fracture and excessive wear on opposing teeth are considered among the major weaknesses. Therefore, new CAD-CAM materials have been developed to combine the advantageous properties of polymers that are not brittle and have the superior aesthetic qualities of ceramics (7).

One of these materials is Vita Enamic, a polymer-infiltrated ceramic network (PICN) fabricated under high temperature and pressure. Vita Enamic can be easily processed and does not require additional processes that could adversely affect the dimensional accuracy of the restoration, such as ceramic glazing or crystallization. In addition, their biomimetic properties similar to the structure of teeth make these materials resistant to high occlusal forces (8).

Another material produced as an alternative to CAD-CAM ceramics is CAD-CAM composites. These materials are fabricated with polymerization under high pressure and temperature, which results in improved mechanical properties. High temperature and pressure are theorized to decrease the size and number of defects in the composite microstructure while reducing polymerization shrinkage significantly (9). Restorations made from CAD-CAM resin composites are easier to manufacture, have a shorter scraping time, do not require sintering, and can be repaired more conveniently compared with restorations made from CAD-CAM ceramics (10). For this reason, composite blocks that have been developed rapidly in recent years, have lower production costs, and provide good mechanical properties have become an alternative to brittle ceramics that cause serious wear on the opposing teeth and cost more to produce (11). The design of endocrown restorations continues to be a controversial issue in dentistry. Research examining the effect of pulp chamber extension depth on stress distribution has reported inconsistent results. Dartora et al. reported that increased pulp chamber extension depth is beneficial for retention and mechanical performance (12). On the other hand, a similar study found that this will cause fractures (13).

Finite element analysis (FEA) is a dental biomechanical technique frequently used to analyze the stress distribution. Factors such as surface geometry, margin preparation, cavity type, material properties, and loading conditions are determined by the researcher to examine the stress distribution (14).

In vitro and clinical evidence required to determine which of these CAD-CAM materials is more effective in restoring endodontically treated teeth is lacking. Therefore, the current study aimed to evaluate the effect of CAD-CAM materials (ceramic, PICN, and composite resin) and the pulp chamber extension depth on the biomechanical behavior of molar endocrowns in an in vitro fashion with three-dimensional FEA. The null hypothesis suggested that the pulp chamber extension depth and different materials used would not affect the stress distribution on restorations and teeth.

## Materials and Methods

The three-dimensional (3D) geometry of tooth #26, obtained with a dental tomography (DA1) device for periodontal reasons, was scanned using cone beam computerized tomography (CBCT) with Morita 3D Accuitomo 170 (J. Morita Mfg. Corp., Kyoto, Japan). The size of the imaging volume was a cylinder with a diameter of 40 × 40 mm in the X-ray rotational center. The images were captured under the following conditions: exposure to 90 kVp X-ray tube voltage and 5 mA electric current, which are standard parameters that can be changed for different subjects. The exposure time parameters for the images were 160 qm and 17.5 s. The 3D geometry created with Geomagic Design X 2020.0 software was divided into surfaces, and the required adjustments were made. The periodontal ligament (PDL) was not designed. The pulp in the root canal was replaced with gutta-percha to simulate an endodontically treated molar. The dental model was placed in the coordinate system in such a way that the x-axis identified the buccolingual direction, the y-axis identified the mesiodistal direction, and the z-axis pointed upward. Two different cavities, that is, pulp chamber extension depths, were modeled with Solidworks 2013 software (SolidWorks Corp., USA): 2.5 mm (Model A) and 3.5 mm (Model B) (Figs. 1 and 2).

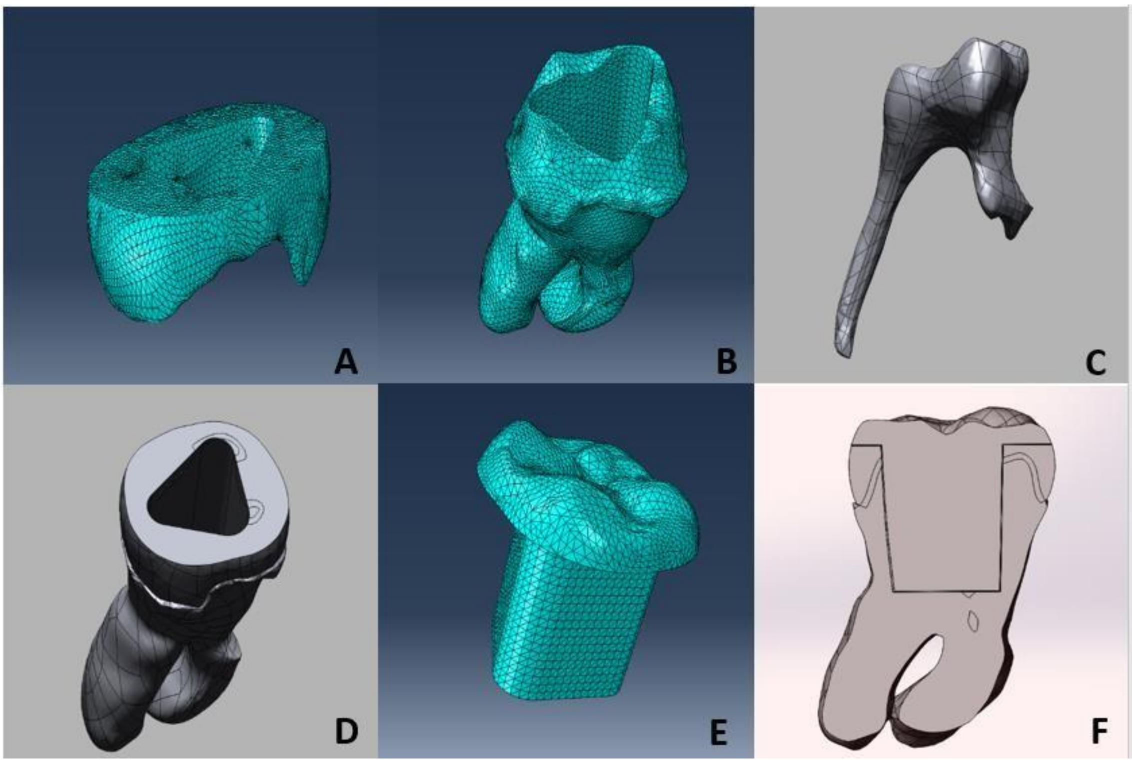



Figure 1. Enamel (A), dentin (B), pulp (C), cement (D), restoration (E), and model (F) prepared for Model A

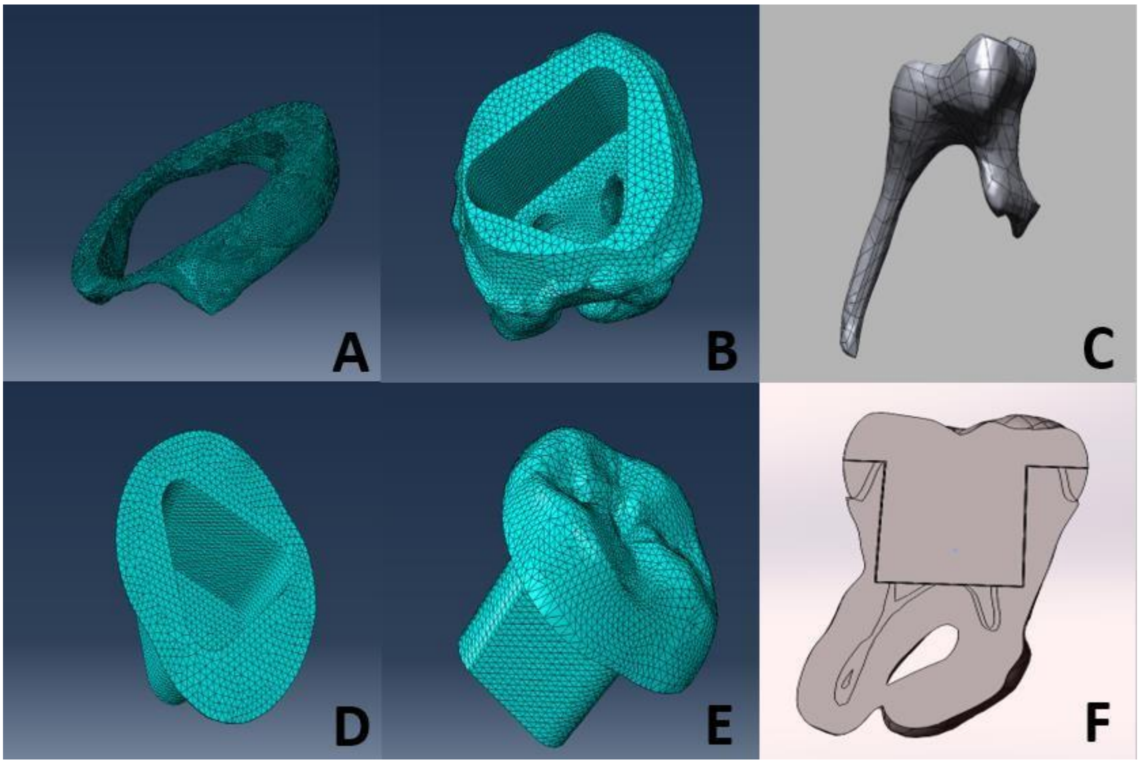



Figure 2. Enamel (A), dentin (B), pulp (C), cement (D), restoration (E), and model (F) prepared for Model B

The following three groups were used in this study depending on their CAD-CAM materials: IPS e.max CAD (EMX; Ivoclar Vivadent AG), Vita Enamic (VE; VITA Zahnfabrik), and Lava Ultimate (LU; 3M ESPE). In addition, the following two subgroups were used on the basis of their cement type: NX3 and MaxCem Elite Chroma (MX). The mechanical properties of the materials and structures used in this study are given in Table 1. The number of elements and nodes is explained in Table 2 based on each model.

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

| Material | Modulus of elasticity (GPa) | Poisson's ratio | Vol. shrinkage (%) | Linear thermal expansion coefficient | Tensile strength (MPa) | Adhesive bond strength to dentin (MPa) |
|---|---|---|---|---|---|---|
| Dentin (15) | 18.6 | 0.31 | | | | |
| Enamel (16) | 84 | 0.33 | | | | |
| Gutta-percha (15) | 0.69(×10-3) | 0.45 | | | | |
| Vita Enamic (VE) (17) | 30 | 0.23 | | | | |
| IPS e.max CAD (EMX) (18) | 95 | 0.23 | | | | |
| Lava Ultimate (LU) (15) | 12.7 | 0.45 | | | | |
| NX3 (15) | 7.44 | 0.35 | 4.88 | 0.0165 | 51.9 | 33.8 |
| MaxCem Elite Chroma (MX) (15) | 4 | 0.35 | 6.05 | 0.0207 | 46.5 | 23.7 |

**Table 2.** Nodes and elements for tested groups

| Model | Total Elements | Total Nodes | Mesh Type |
|---|---|---|---|
| 3.5 | 598584 | 880674 | Quadratic tetrahedral elements of C3D10 |
| 2.5 | 376312 | 559281 | Quadratic tetrahedral elements of C3D10 |

Tensile distribution was investigated using the finite element stress analysis method in Abaqus software (2020 Dassault Systèmes Simulia Corp., Johnston, RI, USA). The restorative materials used in this study were included in the simulation as isotropic linear elastic materials. Periodontal ligament and jawbone were not included in the analysis, and a total force of 600 N was applied to the models. Maximum principal stress (MPa) values were examined to evaluate the effects of the restoration design, material type, and cements used on of endocrowns.

## Results

In the present study, two cavities designed with different pulp chamber extension depths were restored with three different CAD-CAM materials and cemented in two different ways. Maximum principal stress (MPa) values were used to assess the stress distributions on the restoration, enamel, and dentin under force (Figs. 3 and 4).

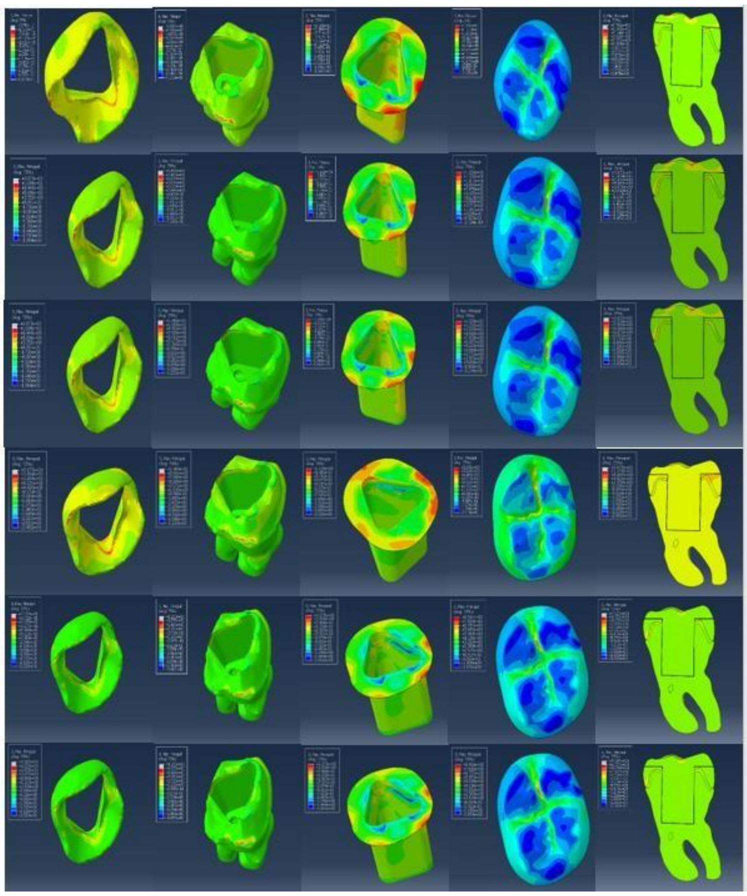


Figure 3. Patterns of maximum principal stress distribution by restorative material and cement type under a force of 600 N for Model A. Columns represent enamel, dentin, cement, restoration, and model, respectively, and rows refer to EMX (MX), EMX (NX3), LU (MX), LU (NX3), VE (MX), and VE (NX3), respectively.

The maximum principal stress (MPa) values for restoration, enamel, and dentin in models A and B under the loads are presented in Table 3, Figure 5, Table 4, and Figure 6, respectively. The highest stress values for both model groups were on the enamel. The maximum stress on the enamel was measured when MX cement was used in the Lava Ultimate material in Model B. (Pmax: 71.76 MPa). The minimum stress on the enamel was measured when the NX3 luting cement was used in the EMX material in Model A (Pmax: 9.763 MPa). The highest and lowest stress values in dentin were measured in the Model B, VE (Pmax: 35.420 MPa) and Model A, EMX (Pmax: 8.985 MPa) groups, respectively.

The highest stress value was measured on enamel and VE material for both models A and B when the NX3 cement was used. The maximum stress formed when using the MX cement; it was measured on the enamel and the LU material in model A (Pmax: 71.76 MPa) and in the VE material on dentin in model B (Pmax: 34.32 MPa).

Materials with a higher elastic modulus have higher stress values on the restoration surface, while the stress values they transmit are lower. Materials where the elastic modulus is close to the dentin have more homogeneous stress distributions within the restoration. This result is consistent with the literature (19).

Table 3. Maximum principal stress (MPa) values in restoration, enamel, and dentin under loads for Model A

| Resin cement | Restorative material | Restoration | Enamel | Dentin |
|---|---|---|---|---|
| | EMX | 13.000 | 37.920 | **9.099** |
| MX | LU | 6.027 | 71.760 | 14.880 |
| | VE | 8.504 | 70.570 | 12.330 |
| | EMX | 12.540 | 28.730 | 8.985 |
| NX3 | LU | 5.932 | 56.750 | 14.840 |
| | VE | 8.305 | 57.950 | 12.270 |

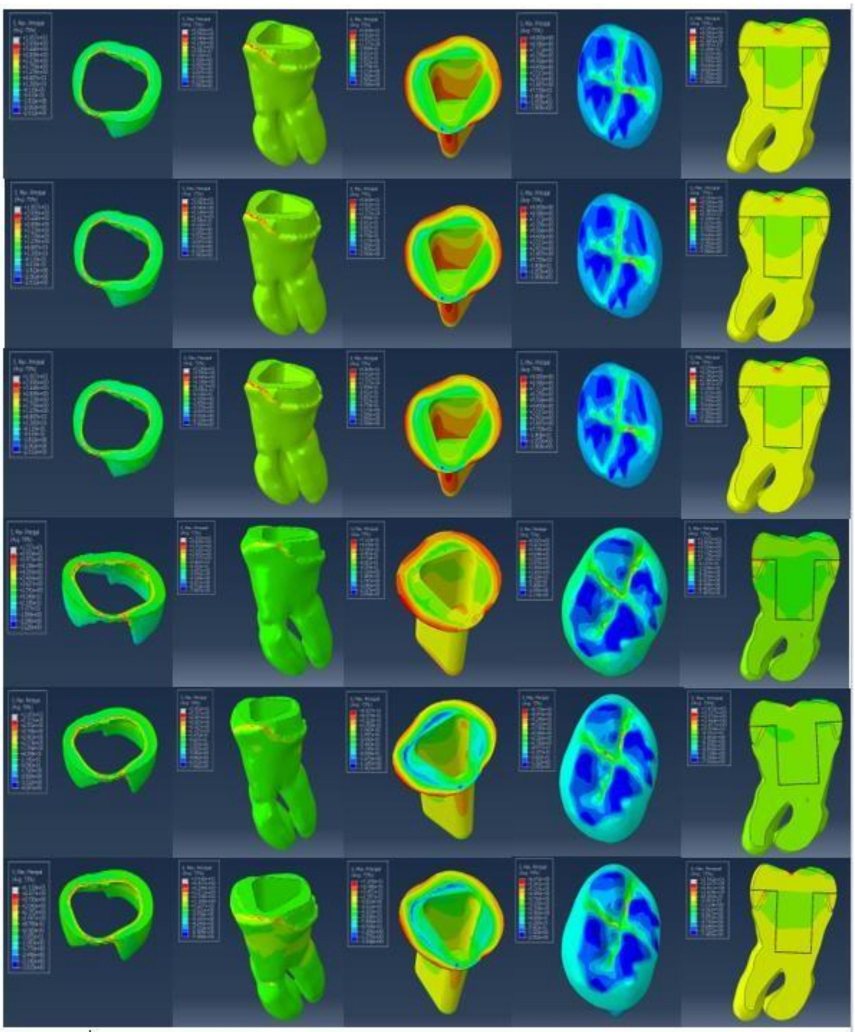
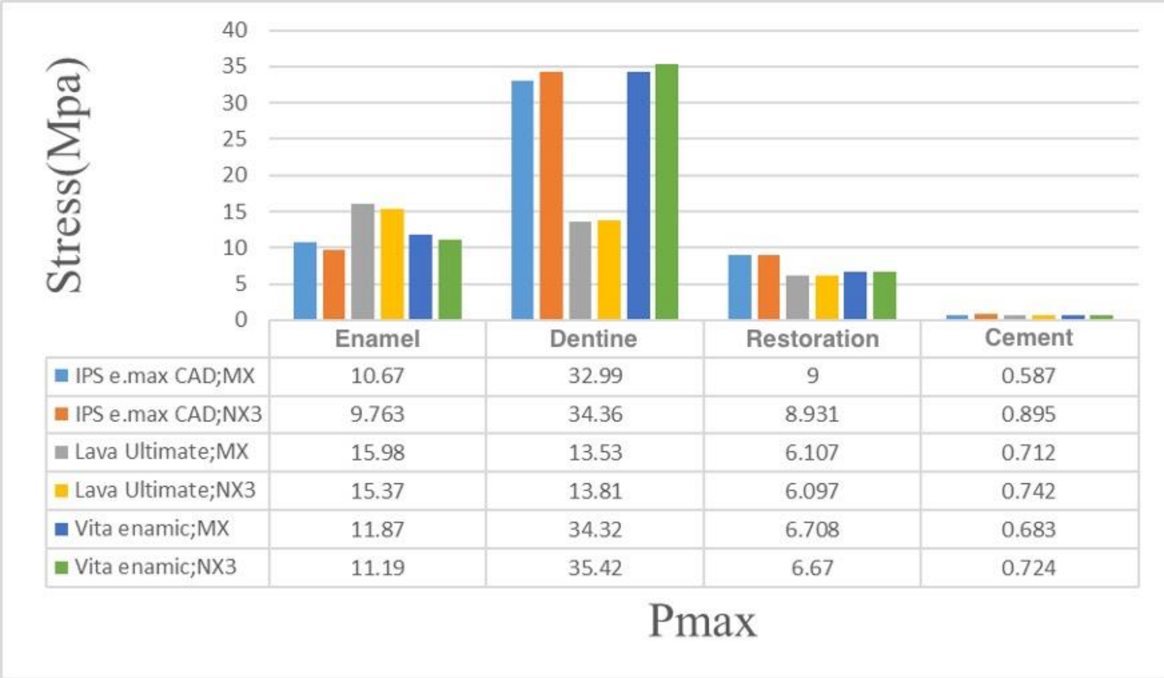


Figure 4. Patterns of maximum principal stress distribution by restorative material and cement type under a force of 600 N for Model B. Columns represent enamel, dentin, cement, restoration, and model, respectively, and rows refer to EMX (MX), EMX (NX3), LU (MX), LU (NX3), VE (MX), and VE (NX3), respectively.

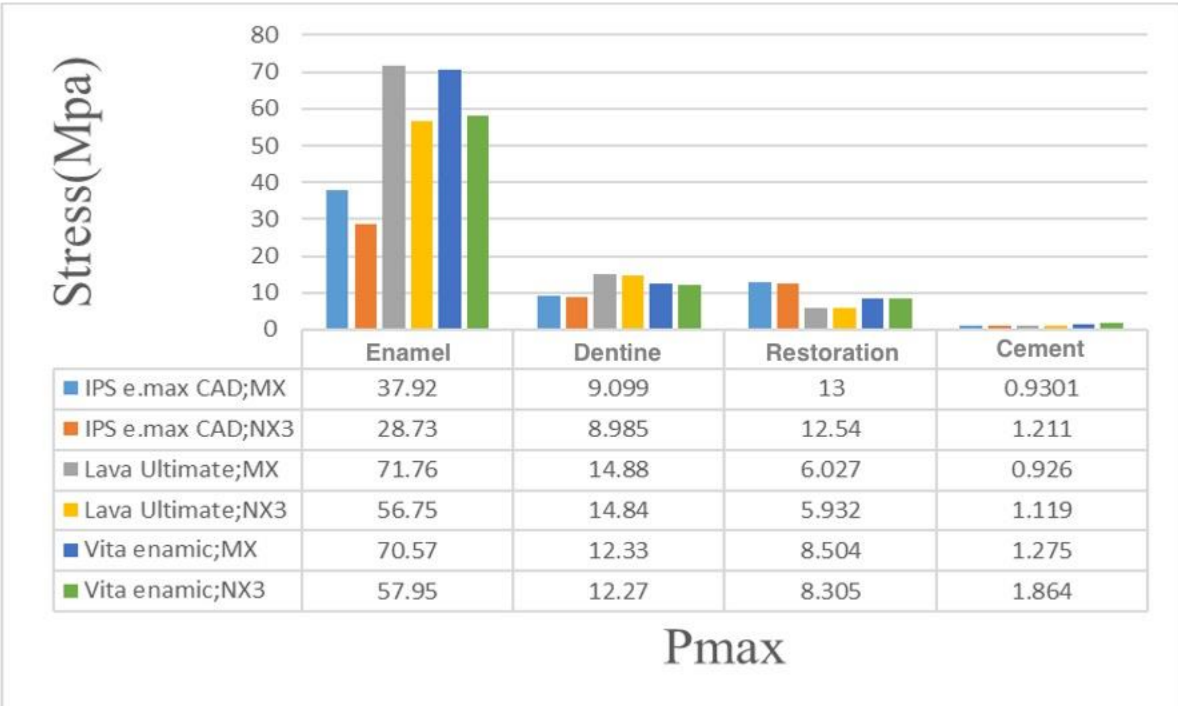
Table 4. Maximum principal stress (MPa) values in restoration, enamel, and dentin under loads for Model B

| Resin cement | Restorative material | Restoration | Enamel | Dentin |
|---|---|---|---|---|
| | EMX | 9.000 | 10.670 | 32.990 |
| MX | LU | 6.107 | 15.980 | 13.530 |
| | VE | 6.708 | 11.870 | 34.320 |
| | EMX | 8.931 | 9.763 | 34.360 |
| NX3 | LU | 6.097 | 15.370 | 13.810 |
| | VE | 6.670 | 11.190 | 35.420 |




| | Enamel | Dentine | Restoration | Cement |
|---|---|---|---|---|
| IPS e.max CAD;MX | 10.67 | 32.99 | 9 | 0.587 |
| IPS e.max CAD;NX3 | 9.763 | 34.36 | 8.931 | 0.895 |
| Lava Ultimate;MX | 15.98 | 13.53 | 6.107 | 0.712 |
| Lava Ultimate;NX3 | 15.37 | 13.81 | 6.097 | 0.742 |
| Vita enamic;MX | 11.87 | 34.32 | 6.708 | 0.683 |
| Vita enamic;NX3 | 11.19 | 35.42 | 6.67 | 0.724 |

Figure 5. Graphical representation of maximum principal stress values for Model A




| | Enamel | Dentine | Restoration | Cement |
|---|---|---|---|---|
| IPS e.max CAD;MX | 37.92 | 9.099 | 13 | 0.9301 |
| IPS e.max CAD;NX3 | 28.73 | 8.985 | 12.54 | 1.211 |
| Lava Ultimate;MX | 71.76 | 14.88 | 6.027 | 0.926 |
| Lava Ultimate;NX3 | 56.75 | 14.84 | 5.932 | 1.119 |
| Vita enamic;MX | 70.57 | 12.33 | 8.504 | 1.275 |
| Vita enamic;NX3 | 57.95 | 12.27 | 8.305 | 1.864 |

Figure 6. Graphical representation of maximum principal stress values for Model B

## Discussion

The current in vitro study aimed to examine the effect of different designs and materials on the biomechanical behavior of endocrown restorations. The null hypothesis was rejected due to the differences in stress distributions on both the tooth and the restoration depending on the design and materials used.

Ceramics have good mechanical and optical properties due to their chemical stability, as well as superior biocompatibility. However, they are difficult to repair once the dental restoration is completed. Although direct composite resins are easier to repair, they have lower biocompatibility and mechanical properties than ceramic restorations. Therefore, CAD-

CAM hybrid composites have been introduced to take advantage of both the elastic modulus properties of composite resins similar to dentin and the aesthetic features of feldspathic ceramics for restorations (20).

FEA is widely preferred in dental biomechanical research to analyze the stress distributions in oral tissues and to predict the clinical performance of dental restoration (21). The FEA results demonstrated that the type of material affects the stress distribution of molar endocrowns. The results of the current study indicate that the maximum principal stress values are higher in endocrowns fabricated from materials with a higher elastic modulus (EMX: 95 MPa) compared to those produced with materials with a lower elastic modulus (VE: 30 MPa, LU: 12.7 MPa). This result is consistent with the literature (3).

Gresnigt et al. evaluated the effect of axial and lateral forces on the mechanical properties of IPS e.max endocrowns. They determined that lithium disilicate endocrowns can be considered the best restorative material due to their micromechanical and adhesive properties (22). However, Albero et al. reported that PICN materials may be preferred for the restoration of posterior teeth, as these materials offer stiffness and an elastic modulus similar to natural teeth (23). Compared to the EMX material, the composite resins (LU: 12.70 GPa) with a similar elastic modulus to dentin exhibited more flexible behavior under the same load in the current study. In addition, the endocrown fabricated from the LU had a more homogeneous stress distribution (Fig. 3). This result suggests that endocrowns made from composite resins can be used for longer durations (24). The differences resulting from using resin cements as luting agents are negligible.

The current study found that the increase in the pulp-chamber extension depth reduced the stress on the restoration. This can be explained by the increase in the thickness of material corresponding to the occlusal loads and the surface area where the stress is distributed. However, it should be noted that taking the measurement and adapting the restoration based on the cavity to be prepared is difficult. Gaintantzopoulou et al. stated that increasing the intraradicular extension significantly increases the marginal gap in endocrown restorations (25). The depth of the pulp-chamber extension for the endocrown and the size of the surface area for adhesive retention are directly proportional to the successful transmission of chewing forces to the root. However, a 5 mm extension depth may damage the pulp-chamber floor of the mandibular molar depending on the anatomical conditions (26, 27). These results suggest that the stress may intensify in the pulp-chamber extension of the restoration due to chewing force and may result in fracture in the future. Particularly in cases where the pulp-chamber floor is weak and further complicated by furcation involvement, deeper pulp-chamber extensions are not deemed appropriate.

A limitation of the current study is that the in vitro test cannot fully simulate in vivo conditions (e.g., the periodontal ligament has not been modeled). However, a recent study did not report any significant difference between the fracture strength of endodontically treated teeth in groups with and without periodontal ligaments (24). During the modeling, we assumed that the dental tissue adhered perfectly to the endocrown restoration and was homogeneous. However, homogeneous and isotropic materials cannot be obtained in vivo. The present study analyzed the stress distribution in mandibular molar endocrowns under vertical static loads. Therefore, further in vitro research should be conducted, and clinical performance should be evaluated under different loading conditions.

## Conclusions

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

1. The stress on the endocrowns fabricated from the LU is lower.
2. Increasing the depth of the pulp-chamber extension increased the surface area and distributed the stress on the restoration homogeneously. However, this is not recommended in cases where the pulp-chamber floor is weak and further complicated by furcation involvement.

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

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