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ORIGINAL RESEARCH

Influence of Restoration Height and Masticatory Load Orientation on Ceramic Endocrowns

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ABSTRACT

Aim: Endocrown restorations are an alternative to restore endodontically treated teeth. Due to the fact that in the literature it is recommended a remnant of 1.5 mm, different heights of endocrown were elaborated and analyzed, obtaining possible faults and their location. This study aimed to evaluate the mechanism of stress distribution in the tooth/restoration set, varying two factors: "restoration height"—three levels, and load application—two levels (oblique or axial), totaling six groups.

Materials and methods: For finite element analysis (FEA), a maxillary premolar was modeled with an endodontic treatment. Then, this template was triplicated and each copy received an endocrown restoration of different heights: G6 (4.5 mm), G7 (5.5 mm), and G8 (6.5 mm). The models were exported in STEP format to analysis software (ANSYS 17.2, ANSYS Inc.). During preprocessing, the solids were considered isotropic, linearly elastic, and homogeneous. Initially, a load (300 N) was axially applied in the central fossa region. For a second evaluation, an oblique load (300 N) was applied on the grinding slope of functional cusp. System fixation occurred at the base of polyurethane cylinder. Results were evaluated through maximum principal stress (MPS).

Results: For axial load, lower stress values were generated in all groups. For oblique load, G8 showed a higher stress concentration in the cement layer and root dentin.

Conclusion: When an endocrown restoration is performed, there is a tendency of failure in the cement line and in the root directly proportional to its size. However, regardless of the size of the element to be reconstituted, the axial direction of the masticatory loads tends to decrease stress concentration.

Clinical significance: When performing an endocrown restoration, care must be taken with its high regardless the tooth remnant high, altering even the anatomical angulations of the occlusal face, when necessary, to avoid stress concentration in thick areas.

Keywords: Dental restoration failure, Dental stress analysis, Finite element analysis.

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INTRODUCTION

Teeth with extensive coronary destruction are a challenge for restorative dentistry. These cases usually require endodontic treatment so that intraradicular retainers (RIRs) can be anchored and thus support the restoration.[1,2] However, the use of RIR can cause a negative effect on endodontically treated teeth, reducing their resistance to fracture.[3] After cementation of the retainer in these remaining teeth, they are usually restored with total crowns requiring preparation with tissue removal, which promotes greater fragility in the previously compromised structure.[4,5] Thus, alternative and more cautious interventions, such as endocrown restorations have been a rehabilitation option.[6] One of the advantages presented by endocrown restoration is conservation of the remaining dentin, since preparation does not require removal of intraradicular gutta-percha, restricting anchorage at the pulp chamber.[7] The endocrown consists of a monolithic restoration, manufactured by computer-aided design/computer-aided manufacturing technology (CAD/CAM) or vacuum injection technique. Currently, CAD/CAM technology has attracted attention from most health professionals, mainly dentists, due to its practicality and high-level results, allowing a more adequate adaptation of the prostheses in general.[8]

For confection of endocrowns, the first choice of machinable materials have been lithium disilicate and composite resins, with the lithium disilicate being more resistant to fracture than the composite resin.[9] In view of this, this study chose to use a recent zirconia-reinforced lithium silicate (ZLS) material as an alternative. This material has emerged as an option for lithium disilicate[10] since its mechanical properties, such as fracture toughness, hardness, and elastic modulus are superior.[11] Due to its high translucency and favorable resistance, this material has been used in the manufacture of monolithic crowns.[6,12]

Studies have argued that a minimal remaining height of 1.5 mm for clinical crowns promotes adequate adhesion to retain the endocrown,[13] and a more conservative coronary preparation tends to promote better performance due to the decrease in the restoration size.[14] However, maintaining the clinical condition of 1.5 mm of remaining coronary height/space suggested by the literature combined with the possibility of different sizes of premolar clinical crowns (6–8 mm)[15] generates doubt about load distribution in this restorative modality. Although the height of the dental element is not clinically controlled, masticatory load is a factor that can be modified by occlusal contact direction in axial regions or larger areas,[16] less prominent dental anatomy and lower cusps. This axial direction is often empirical and not necessarily followed, since there is a lack of scientific material that shows whether such care would exert a difference or not in the prognosis of this treatment. In order to elucidate the stress generated in dental structures, papers using FEA are widely used[14,17] as a mathematical tool that evaluates the biomechanical behavior of restorations. Thus, the purpose of this study was to evaluate the influence of different heights and load type applied on the biomechanical behavior of endocrowns on a dental remnant (1.5 mm). The hypotheses of this work were that: (1) The height of the restoration and (2) the load type applied do not influence the stress distribution on the structures.

MATERIALS AND METHODS

Finite Element Analysis

The study was conducted using the three-dimensional (3D) FEA method using ANSYS analysis software (ANSYS 17.2, ANSYS Inc.) to evaluate the stress concentration in cement line, in root dentin, and in endocrowns with different heights: 4.5, 5.5, or 6.5 mm[15] under different load applications (oblique or axial). These heights were evaluated in an attempt to simulate the mean heights of the elements under study.[15] Groups were divided into G6 (4.5 mm), G7 (5.5 mm), and G8 (6.5 mm). Initially, an FEA 3D mathematical model simulating a previously validated maxillary premolar was selected.[16,18] Roots were adapted to simulate the biomechanical preparation of the endodontic treatment, the space was filled by the obturator material, and the rehabilitated element with an endocrown restoration was created through Rhinoceros CAD software (version 5.0SR8 McNell). The periodontal ligament (PDL) was modeled based on the root with a thickness of 0.3 mm. This model was replicated, creating two more models to simulate a total of three endocrown restorations with different heights (Fig. 1). The restoration was restricted to the pulp chamber (2 mm) without intraradicular gutta-percha removal.[5] The cement line was created to occupy all the space between the restoration and the dentin, with 0.3 mm thickness.[17] The structure modeling sequence is shown in Figure 1. Next, the models were exported in STEP format to the analysis software (ANSYS 17.2, ANSYS Inc.) where meshes were made using tetrahedral elements (Fig. 2A). All materials were considered isotropic, homogeneous, and linearly elastic. The properties required for a static structural mechanical analysis are summarized in Table 1.[19-23] During the finite element modeling, a mesh was generated and refined, resulting in a more precise solution. In this case, the convergence test was based on the number of nodes (240,536) and elements (136,576) obtained by the mesh convergence test, with 10% of difference between the values presented at a certain point in the mesh. The fixation occurred on the cylinder surface in order to receive the axial and oblique loads of 300 N (Figs 2B and C). The axial load was applied to the main groove while the oblique load was applied to the grinding slope of the functional cusp. Values of MPS were evaluated through colorimetric graphs (Fig. 3) and stress peaks for each group through bar graphs (Graph 1).

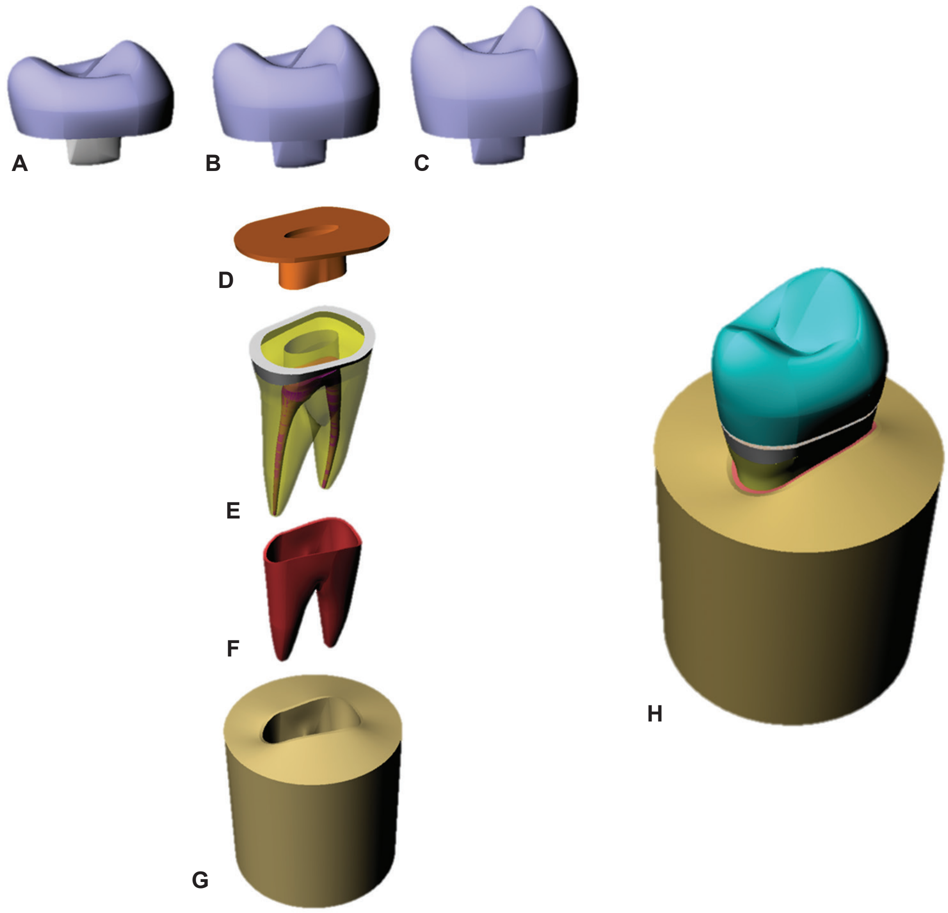
RESULTS

Oblique Load

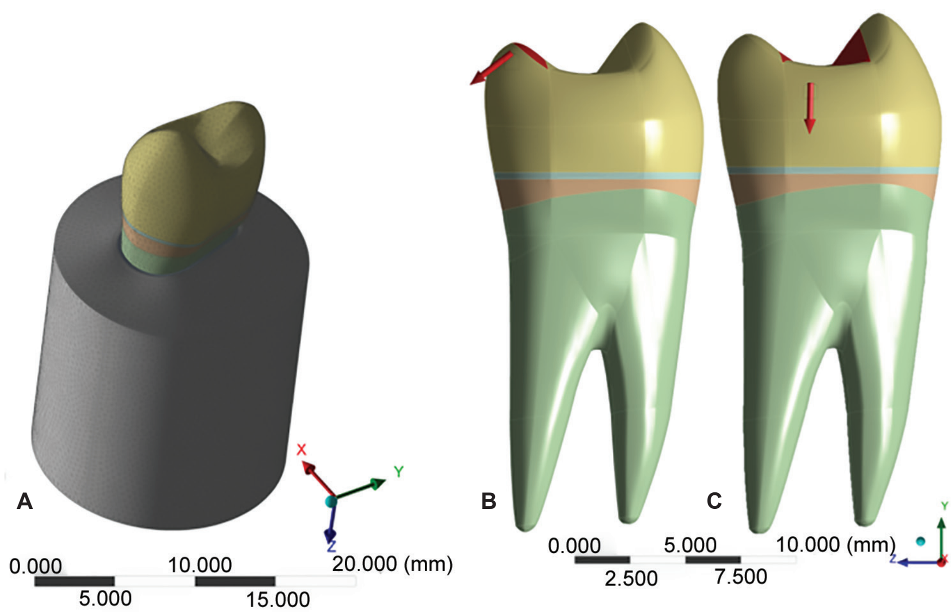
The data obtained by FEA show that there was a difference in the restorations' biomechanical behavior during an oblique load application, with G8 group presenting the worst mechanical performance, and G6 group had the best performance (Graph 1). For cement line and root dentin (Figs 3A to C), the higher the restoration, the higher the stress concentration.

Axial Load

Considering axial loading, a lower concentration of MPS was observed for endocrown, cement line, and root dentin. Although the stress difference under axial load is small between the different evaluated heights (Figs 3D to F), the thicker the restoration is, the greater its resistance to fracture when subjected to a compressive load. Differences greater than 10% of the obtained



Figs 1A to H: Scheme for producing the models. Endocrown of (A) 4.5 mm, (B) 5.5 mm, (C) 6.5 mm, (D) cementation line, (E) obturated root, (F) PDL, (G) polyurethane block, (H) dental element fixed to the polyurethane block



Figs 2A to C: (A) Generation of meshes. Application of (B) oblique load and (C) axial load

Table 1: Elastic modulus (E) and Poisson's ratio of the materials used in this study

Structure/material	*E (GPa)*	*Poisson ratio*
Zirconia-reinforced lithium silicate	70[19]	0.23[19]
Dentin	18.6[20]	0.31[20]
PDL	0.069[14]	0.45[14]
Resinous cement	7.5[21]	0.23[22]
Gutta-percha	0.69[23]	0.45[23]

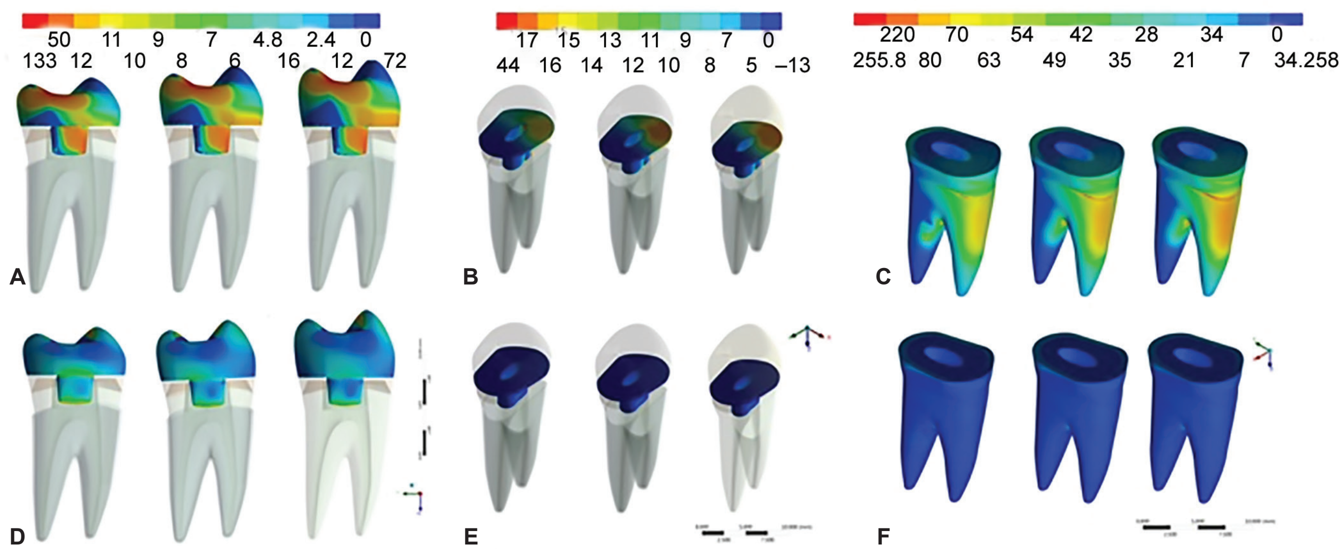
stress peaks were assumed to be significant in the three evaluated structures (Graph 1) due to the criteria of the obtained convergence test. The highest stress concentration in the cement line and root dentin occurred for G8 under oblique loading.

DISCUSSION

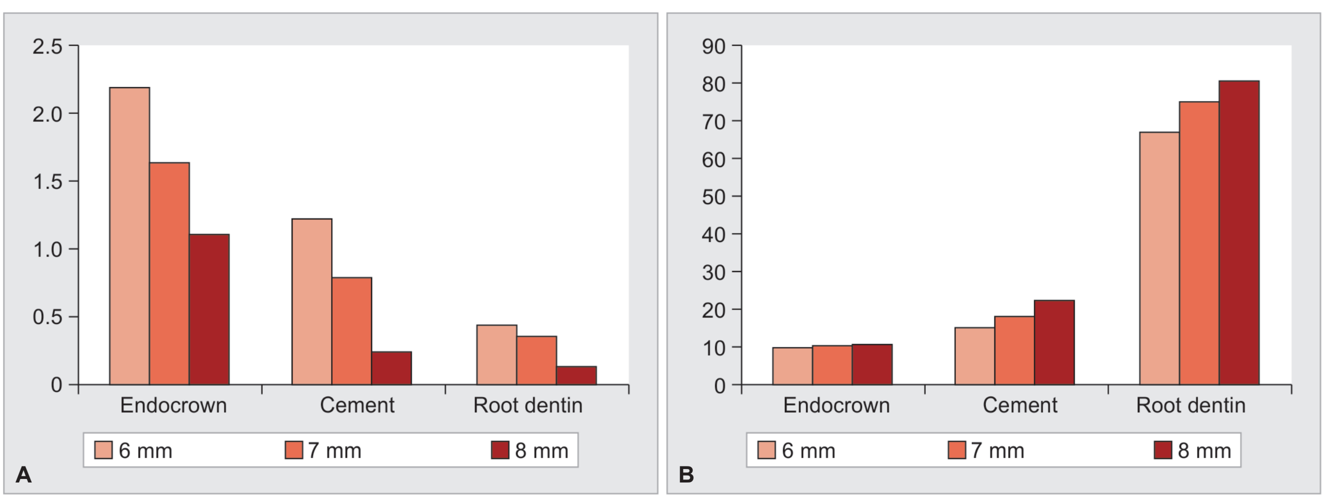
The purpose of this study was to evaluate the mechanism of stress distribution in the tooth/restoration set varying the restoration height (three levels) and the applied load type (two levels). Through FEA, it was observed that the hypotheses were partially rejected. After modeling and load application, the model was analyzed focusing on endocrown restoration, cement line, and root dentin. Results also demonstrate that applied load direction was more influential in the results than "restoration height."

The FEA consists of a mathematical methodology widely used in dentistry[14,17] aiming to evaluate the biomechanical behavior of the structures. By constructing 3D computational models, it is a low-cost method that provides mathematical analysis data. Despite the fact that materials are free from defects, this methodology is widely used in evaluating the behavior of endodontically treated teeth.[14,17]

The restorative material chosen (zirconia-reinforced lithium silicate) is a material that has few studies, but already has an indication and case report of its use in



Figs 3A to F: The MPS (MPa) in (A, D) endocrown, (B, E) cementation line, and (C, F) root dentin under axial and oblique load respectively



Graphs 1A and B: Bar graph with peaks of MPS (MPa) in the endocrown, cement line, and root dentin, according to the load application: (A) axial and (B) oblique load endocrown restorations.[13] The reliability generated by the use of CAD/CAM materials to manufacture this type of restoration is mainly due to the chemical adhesion of glass matrix and dental substrate.[4] To achieve a good prognosis, the adhesive restorations are indicated for use in dental enamel, and promotes the need for a minimum remaining amount containing enough of this tissue in the case of 1.5 mm endocrowns starting from the cementoenamel junction.[4]

Because there are anatomical variations among individuals of the same society, several teeth heights can be found,[15] and thus restorative material cemented under the same amount of remaining enamel may be different depending on the occlusal height. For this reason, the height factor was the focus of this work. In addition, endocrown restorations may vary their extent at the pulp chamber level in order to promote greater restoration retention. However, when this characteristic was evaluated,[14] it was observed that the longer the restoration is in the pulp chamber, the greater the lever arm is when subjected to an oblique load, and consequently the greater the number of restorative treatment failures.

Oblique Load

Regarding the results for oblique load, it was observed that height factor did not influence the distribution of tensions between the evaluated endocrowns (Fig. 3A). This may be justified by the fact that the crunching slope anatomy of the loaded cusp had little difference between the groups, since the restoration thickness only increased in the cervico-occlusal region. Thus, the normal component action of the applied load was practically unchanged, and also the reaction exerted by the restoration (Fig. 3A). Thus, the biomechanical behavior was similar, which might not occur if the buccal-lingual dimension of the restoration was altered or the anatomy is drastically modified.

For cement line as well as for root dentin, it was observed that tensile stress was directly proportional to the restorations' height (Figs 3B and C and Graph 1B). These results corroborate a previous study[5] that the greater the restoration volume under oblique load, the greater the stress concentration in root dentin, which may lead to a catastrophic failure. However, it was also observed that a greater tendency for adhesive failure occurred at higher height (Fig. 3B), with higher stress concentration in cement line. Nevertheless, it is important to note that the energy required to compromise the adhesive bond between restoration and dentin is significantly lower than a cohesive dentin failure (Fig. 3C).

Axial Load

In evaluating the results under axial load, it is possible to observe an inverse result: The larger the height of the endocrown, the lower the stress concentration in the three structures under evaluation (Figs 3D to F). Considering this type of loading, the restorations are predominantly subjected to a compressive load, so the difference between groups was rather subtle and decreased as the height increased (Graph 1A), since the focus of the results required by the performed analysis was MPS, and not minimum principal stress.

Stress concentration being inversely proportional to the height under axial load can be explained by the fact that the restoration volume is directly associated with the fracture resistance, independent of the material.[18] Although there is little difference between the stress values under axial load, they are significantly relevant since they numerically express a difference greater than 10% between the results of each group. In addition, the greater the restoration's height, the less compressive stress is generated in the remaining dentin,[14] suggesting a lower probability of failure in G8 when compared with the other groups.

CONCLUSION

When an endocrown restoration is performed, there is a tendency of failure in the cement line and in the root directly proportional to its size. However, regardless of thesize of the element to be reconstituted, the axial direction of the masticatory loads tends to decrease stress concentration..

Clinical Significance

When performing an endocrown restoration in premolar, the non-axial loading should be avoid to reduce the stress on the cement.

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