# Effect of central retainer shape and abduction angle during preparation of teeth on dentin and cement layer stress distributions in endocrown-restored mandibular molars

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To study the effect of central retainer shape and abduction angle during tooth preparation on stress distribution in endocrown-restored molars *via* finite element (FE) analysis, we constructed five FE models with different central retainer shapes and abduction angles. Under an oblique load, the distributions of maximum tensile stress in cervical dentin around the endocrown and on the cement layer, as well as maximum shear stress on the cement layer, were more balanced in the FE model in which the central retainer shape was generated based on the anatomical form of the pulp chamber. Moreover, there were no differences in stress distributions among FE models with different abduction angles. Therefore, the shape of the central retainer should be designed on the basis of the anatomical form of the pulp chamber; abduction angle during tooth preparation does not influence the repair effect of endocrown-restored mandibular molars.

*Keywords*: Cement interface, Endocrown, Finite element analysis, Stress distribution

## INTRODUCTION

Endodontically treated teeth are more prone to fracture, compared with natural teeth, due to the loss of structural integrity. Consequently, restorations partially or completely covering the occlusal surface are necessary to protect the teeth after root canal therapy. The retention modes of occlusal coverage restorations include extracoronal, intraradicular, and intracoronal retention. Extracoronal retention is represented by complete crowns in clinic. Intraradicular retention, which is typically used in association with extracoronal retention, is represented by post-and-cores and crowns. In recent years, some scholars have proposed the use of endocrowns, which primarily rely on intracoronal retention and adhesive cements, to repair endodontically treated teeth, due to the improvement of restorative materials and adhesive technology[1,2]. Compared with traditional prosthetics, the application of endocrowns can reduce the amount of healthy dental tissues that must be removed during preparation, simplify the operation procedure, and shorten treatment time. Furthermore, endocrowns can be used in situations where classical techniques are unsuitable, such as those in which the interocclusal space is limited, the root is short or tortuous, or the root canal is tiny and calcified[3].

Previous studies have suggested that endocrown-restored posterior teeth exhibit robust prosthetic performance[4,5]. Rocca *et al.* found that there were no significant differences in marginal adaptation or fatigue resistance between teeth restored with endocrowns and post-and-cores and crowns[6]. Guo *et al.* suggested that the fracture resistance of endocrown-restored mandibular premolars did not differ from those restored with post-and-cores and crowns[7]; some studies demonstrated superior fracture strength of endodontically treated teeth restored with endocrowns[3,8]. No differences in survival rate were found between molars restored with endocrowns and those restored with traditional methods, according to clinical observation[9].

In situations involving failure, the primary reasons include clinical fracture of repaired teeth and debonding of endocrowns[10,11]. Therefore, it is necessary to study stress distributions in both residual dental hard tissues and cement layers, in order to evaluate the feasibility of restoring coronal damaged teeth with endocrowns. Previous studies have revealed that material type and height of the central retainer influence stress distributions in endocrown-restored teeth[12,13]. Thus far, there has been minimal research regarding the effect of central retainer shape and abduction angle during tooth preparation for repair of endocrown-restored teeth. *In vitro* experiments have shown that fracture typically occurs in cervical dentin adjacent to the endocrown in restored teeth[14,15]. Finite element (FE) analysis also revealed that the highest stress level in dentin is present in the pulp chamber region beneath the endocrown[16]. Thus, we analyzed stress distribution in cervical dentin around the endocrown in this study. Additionally, stress concentration in the inner cement layer between the endocrown and dentin could cause failure of luting cement, leading to the formation of cracks in the cement layer, and may further cause loosening of the endocrown, even detachment with propagation of the crack; in the

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outer cement layer between the restoration and enamel, the failure of luting cement could result in degradation and/or secondary caries in the cement layer. However, although the adhesion strength between ceramic and enamel is superior to that between ceramic and dentin[17], the cement layer has been typically considered to be a whole part in previous studies. In this study, FE analysis was used to determine the effect of central retainer shape and abduction angle of the abutment on stress distribution in both cervical dentin and cement layers. Furthermore, the cement layer was divided into two portions: a portion between endocrown and dentin, and a portion between endocrown and enamel.

## MATERIALS AND METHODS

### *Model building*

The microcomputed tomography data of an intact mandibular first molar, which was extracted for severe periodontitis, were obtained from Peking University School of Stomatology. An interactive medical image control system (Mimics ver.15.0, Materialise, Leuven, Belgium) was used to isolate enamel, dentin, and pulp from each other. The obtained three parts were then imported into the reversing engineering software (Geomagic Studio ver.11.0, Raindrop Geomagic, Research Triangle Park, NC, USA) for materialization, and were assembled together *via* computer-aided design software (CATIA ver.5, BM, Kingstone, NY, USA). Based on the modeling steps described above, an FE model of the mandibular first molar was generated, including its mesio and distal roots, as well as the mesiolingual, mesiobuccal, and distal root canals within them. The model was divided into two portions by the horizontal plane passing the lowest point of cemento-enamel junction. The portion below this plane was surrounded by a 13×17×20-mm cuboid to simulate the alveolar bone around the tooth root, which was connected with a 0.2-mm periodontal ligament. This model represented the intact molar, and was imported into the finite element software (Ansys ver.16.0, ANSYS, Canonsburg, PA, USA).

Ansys software was used to measure the widest distance of the apical foramen and the length of each root canal. The respective lengths of the widest distances of the apical foramina of the mesiolingual, mesiobuccal, and distal root canals were 0.3, 0.35, and 0.5 mm; the respective lengths of the root canals were 11.9, 11.4, and 10.9 mm. After root canal preparation, root canal shapes were simulated by a step-back technique; the root canal spaces were filled with gutta percha and a 1-mm flowable resin coronally.

The horizontal plane passing the lowest point of the occlusal surface was selected and translated 1 mm apically. The FE model was divided into two portions by the horizontal plane. The pulp chamber in the nether portion was modified by mellowing the acute angles. This part was considered the central retainer; together with the coronal portion of the model, it comprised the endocrown, which was connected to the residual dental tissues with a 120-μm cement layer. The thickness of lateral dentin walls around the endocrown was approximately 3 mm. Lithium disilicate reinforced glass-ceramic (IPS e.max CAD, Ivoclar Vivadent, Schaan, Liechtenstein) was selected as the restorative material. This was defined as Model A (Fig. 1a).

In Model B, each crossing angle between the lateral walls of the central retainer was rounded with a 1.5-mm chamfer angle; the empty spaces between endocrown and dentin were filled with composite resin. In Model C, the buccolingual dimension of the central retainer was reduced by 0.5 mm each on both buccal and lingual sides; the free spaces were filled with resin (Fig. 1a).

In this study, the abduction angle was defined as the angle formed by opposing lateral dentin walls. The abduction angle in Model A was set as six degrees. In Models A-0 and A-12, the conditions were identical to those of Model A, with the exception that the abduction angles of abutment were set as 0 degrees and 12 degrees, respectively (Fig. 1b).

All materials and dental tissues (including enamel, dentin, periodontal ligament, and alveolar bone) were set as homogeneous, isotropic, and linear elastic (Table 1). The data came from the previous studies[18-23].

The boundary where the enamel and dentin connected on the coronal surface of the residual dental tissues was determined; it was then used to divide the cement layer into two portions: the portion of cement layer between endocrown and dentin was considered cement 1, and the portion of cement layer between endocrown and enamel was considered cement 2 (Fig. 1c). Perfect adhesions were assumed among the luting cements, ceramic, enamel, and dentin.

### *Boundary constraint and load applied*

The mesio, distal, and basal surfaces of the alveolar bone were fixed. In earlier research, oblique load was proven to be more dangerous to teeth[24]. To simulate the stress conditions of mandibular molars during lateral chewing, a total load of 250 N, with a 45-degree angle to the long axis of the molar, was applied to the lingual incline surfaces of the buccal cusps (Fig. 1d)[25].

### *Stress analysis*

Because dentin was more prone to fracture under tensile stress due to its relatively low tensile strength[26], we focused on analysis of the distribution of maximum principle stress in cervical dentin around the endocrown. In addition to the tensile bond strength, the shear bond strength of the cement layer was suspected to influence the repair effect of the restoration[27]. Thus, distributions of maximum principle stress and maximum shear stress (MSS) were both analyzed in cements 1 and 2.

## RESULTS

### *Stress distributions in dentin around the endocrown and cement layers in Models A, B, and C*

As shown in Fig. 2, in an endodontically treated molar restored with an endocrown (Model A), the maximum

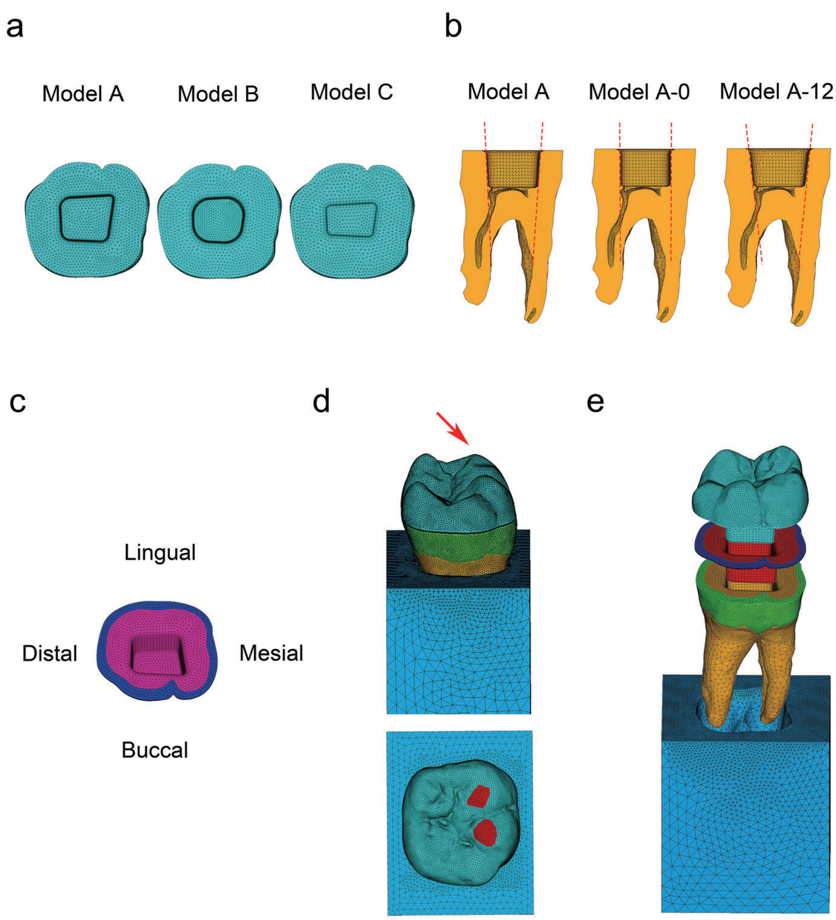


Fig. 1 (a) Endocrowns with different central retainer shapes; (b) Abduction angles of abutment tooth; (c) Cement layers of finite element models (red section represents cement 1, while blue section represents cement 2); (d) Oblique load applied to lingual inclined surfaces of buccal cusps; and (e) Sketch of endocrown-restored molar.

Table 1 Material properties

| Material | Elastic modulus (GPa) | Poisson ratio | Ref. |
|---|---|---|---|
| Enamel | 84.10 | 0.33 | 18) |
| Dentin | 18.60 | 0.31 | 18) |
| Periodontal ligament | 0.07 | 0.45 | 19) |
| Alveolar bone | 1.37 | 0.30 | 19) |
| Multilink Automix | 5.00 | 0.29 | 20) |
| Flowable resin | 5.30 | 0.28 | 21) |
| Gutta percha | 0.07 | 0.40 | 22) |
| IPS e.max CAD | 95.00 | 0.30 | 23) |

tensile stress (MTS) in cervical dentin around the restoration was concentrated at the distolingual angle of the pulp base; notably, the MTS decreased from the lingual side to the buccal side. When the central retainer shape was more rounded (Model B), the stress concentration region was unchanged, while the MTS increased. When the mandibular molar was restored with an endocrown in which the buccolingual dimension of the central retainer was reduced (Model C), no significant difference was found in the distribution of MTS in dentin between Models A and C (Fig. 2a).

Because the cement layer between dentin and endocrown (cement 1) was thin (120-µm) and exhibited low elastic modulus (5 GPa), the MTS distribution

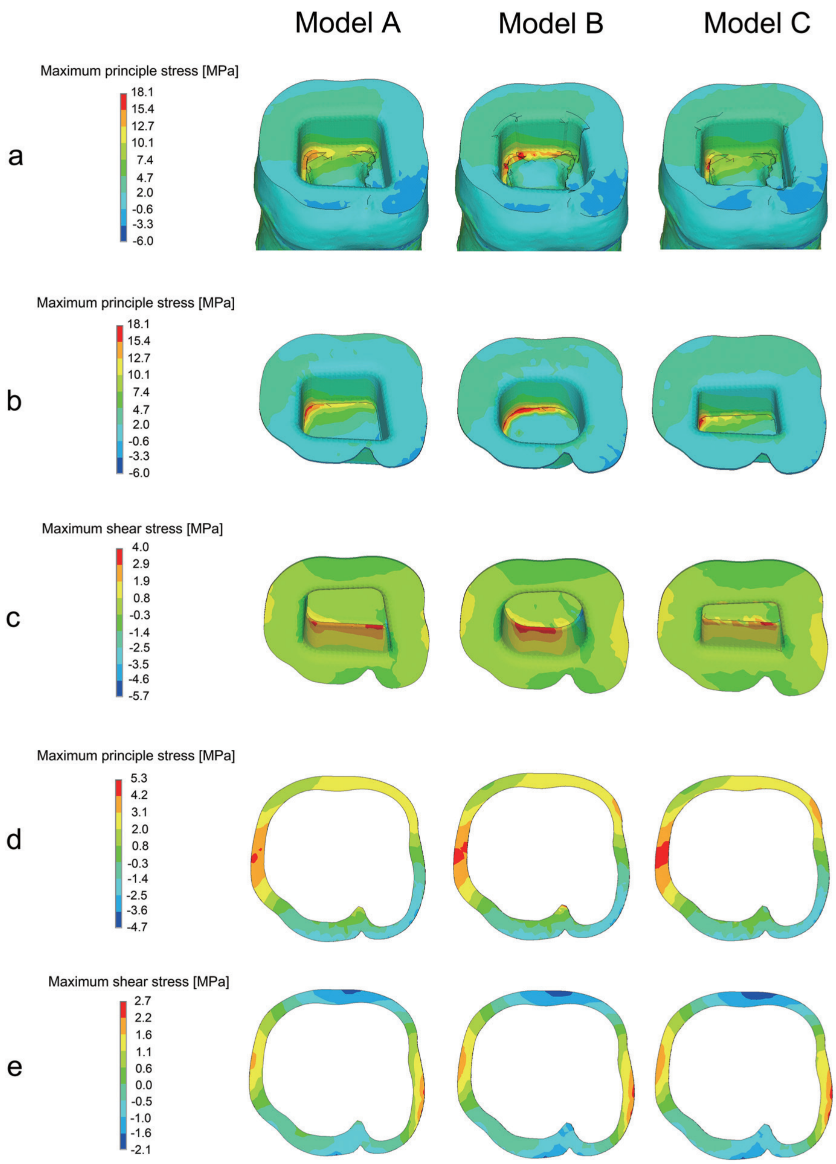


Fig. 2 Distributions (MPa) of (a) maximum principle stress (MPS) in dentin; (b) MPS and (c) MSS in cement 1; and (d) MPS and (e) MSS in cement 2 among Models A, B, and C.

in cement 1 was similar to that in dentin around the endocrown; the MTS was concentrated at the distolingual angle of the pulp base in the FE models. The concentration area of MTS in Model B increased, compared with the corresponding areas in Models A and C (Fig. 2b). A similar tendency for MSS distribution in cement 1 was observed among the FE models. In Model A, the MSS in cement 1 was concentrated at the region adjacent to the junction of pulp base and buccal dentin walls. In Model B, the MSS was concentrated in the same region, and showed an increased concentration area. In Model C, both the location and area of stress concentration were similar to those in Model A (Fig. 2c).

According to Fig. 2d, the MTS in the cement layer between enamel and endocrown (cement 2) was concentrated on the distal side in Model A. When the central retainer shape was more rounded (Model B), the pattern of MTS distribution was unchanged, while the concentration area of MTS increased. In Model C, as the buccolingual dimension of the central retainer decreased, the concentration area of MTS further increased. No obvious difference in MSS distribution in cement 2 was found among the FE models (Fig. 2e).

*Stress distributions in dentin around endocrown and cement layer in Models A, A-0, and A-12*

As described in the previous paragraph, when the

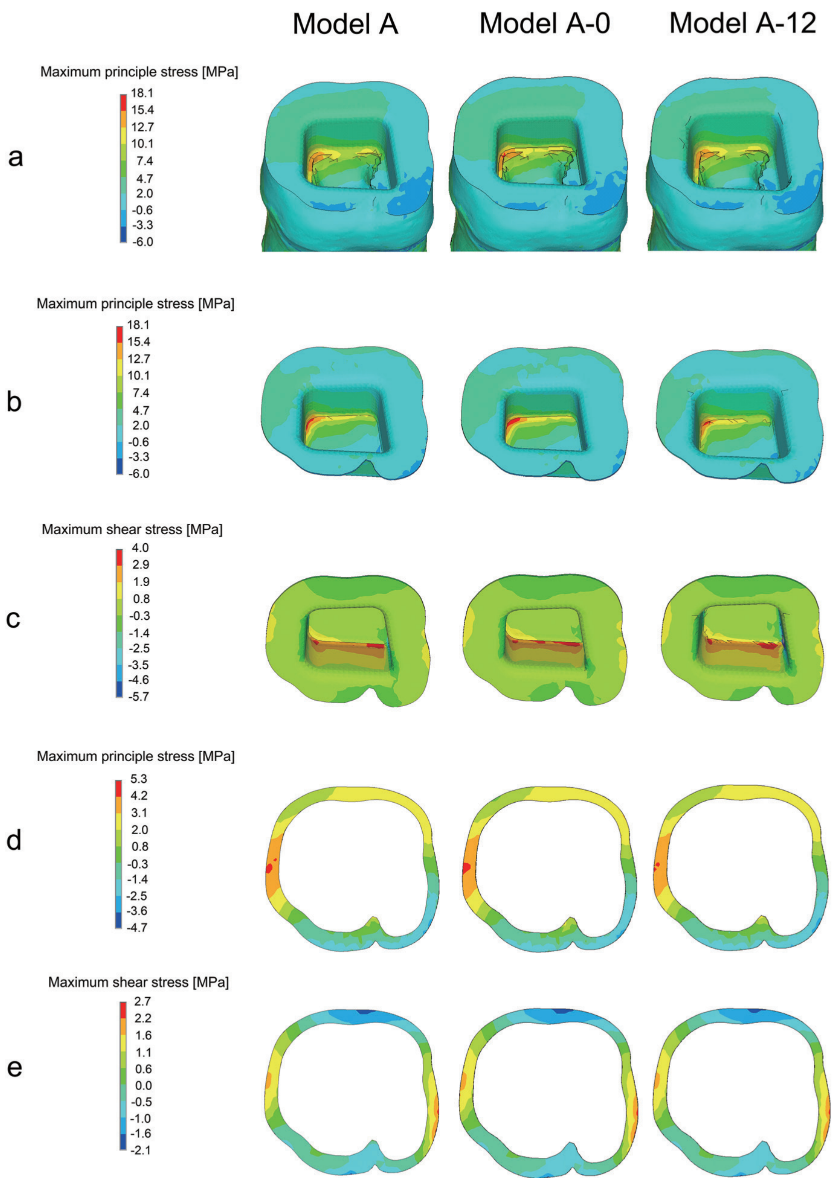


Fig. 3 Distributions (MPa) of (a) MPS in dentin; (b) MPS and (c) MSS in cement 1; and (d) MPS and (e) MSS in cement 2 among Models A, A-0, and A-12.

abduction angle of abutment was set as six degrees (Model A), the MTS in cervical dentin around the endocrown was concentrated at the distolingual angle of the pulp chamber floor; notably, the MTS decreased from the lingual side to the buccal side. The distribution of MTS in cement 1 was similar to that in dentin, such that the stress was concentrated at the distolingual angle of the pulp base. Conversely, the MSS in cement 1 was concentrated in the region neighboring the junction of the pulp base and buccal dentin wall. In cement 2, the MTS was concentrated on the distal sides, while the MSS was concentrated on the mesial and distal sides. When the respective abduction angles were set as 0 degrees (Model A-0) and 12 degrees (Model A-12), neither the locations nor concentration areas of stress in the dentin and cement layers were obviously changed (Fig. 3).

## DISCUSSION

The endocrown has recently been considered an optimal method to restore endodontically treated molars with large coronal area defects. Clinical research found that the survival rate of molars restored with endocrowns reached 87.1% after approximately 3 to 5 years[11], and there was no statistical difference in the survival rate between molars restored with endocrowns and those restored with a traditional prosthesis at the 12-year follow-up[9]. Clinical fracture of the restored teeth and debonding of the endocrown were the two primary reasons identified in unsuccessful treatment.

Fracture typically occurred in cervical dentin around the endocrown in repaired teeth. The results in the current study showed that when the endocrown-restored molar experienced an oblique load, the MTS in cervical dentin was concentrated at the distolingual angle of the pulp base, due to leverage caused by the endocrown; therefore, this region was likely to undergo fracture in the future. In order to reduce the stress concentration, smoothing of acute line angles at the pulp chamber floor was suggested, using resin or glass-ionomers. Instead of designing central retainer shape on the basis of the anatomical form of the pulp chamber, some clinicians have rounded the line angles of central retainers and filled empty spaces between endocrowns and dentin with composite resin. Our results showed that rounding the central retainer of the endocrown would result in greater stress concentrations, rather than reduced concentrations. This may be because the low-elastic modulus resin used in this study was small in size; thus, it could not dissipate a large amount of energy. The stress that was initially concentrated at the corner of the pulp chamber floor was transferred to the neighboring region; this increased the stress concentration area. Thus, we do not suggest rounding of the central retainer, despite the increased fracture risk of remaining dentin or inferior retention of the endocrown. Because the MTS decreased from the lingual side to the buccal side, we reduced the buccolingual dimension of the central retainer and filled free spaces with resin; we suspected that this would reduce the stress concentration. However, there was no obvious change in the stress distribution in cervical dentin around the endocrown. Because an increased interface between different materials may increase the risk of cohesive failure, the central retainer shape should be designed based on the anatomical form of the pulp chamber.

A previous study revealed that endocrowns may become loosened or detached during long-term service. This may be due to internal or external failure of luting cements. In the inner cement layer between the endocrown and dentin (cement 1), the MTS and MSS were concentrated at the junction of pulp chamber floor and lateral walls on the lingual and buccal sides, respectively. Although these regions do not contact the oral environment while the integrity of the cement line is maintained; however, when a crack occurs in the inner cement layer due to the failure of cohesive, it could internally propagate where the stress intensity factor (near the crack tip) exceeds its fracture toughness value, eventually causing adhesive failure. So smoothening of the sharp edge at the base of the pulp chamber, in the preparation for endocrowns, is suggested to reduce the stress concentration in cervical dentin beneath the endocrown, as well as on the cement layer. Because the cement layer exhibited low elastic modulus with a thickness of approximately 100 µm, its buffering effect in the process of transferring stress from the endocrown to dentin could be disregarded. Thus, variations in both MTS and MSS distributions in the inner cement layer among FE models were similar to those observed in dentin: when the central retainer was more rounded, the concentration area in the inner cement layer increased, thus increasing the future risk of adhesive failure. Notably, reducing the buccolingual dimension of the central retainer could not improve stress distribution in the inner cement layer; in contrast, this change expanded the interface.

Our study also revealed that, in the outer cement layer between the endocrown and enamel (cement 2), the MTS was concentrated on the distal side as an oblique load was applied to lingual incline surfaces of buccal cusps. Clinically, the outside luting cements between restorations and enamel have a high probability of direct contact with the oral environment. When adhesive failure occurs, luting cements may degrade and/or secondary caries might occur in the complex oral environment, thus affecting the adhesive effect of endocrown-restored mandibular molars. When the shape of the central retainer was rounded, or the buccolingual dimension was reduced, a resin with low elastic modulus was used to fill empty spaces between the restoration and dentin. Under the same load, deformation of the endocrown was then increased, which resulted in greater stress concentrations in the cement layer on the distal side. Combined with the stress distribution in cervical dentin, as well as on both inner and outer cement layers, these findings support our recommendation that central retainer shape should be designed based on the anatomical form of the pulp chamber.

Optimal retention was found when opposite dentin lateral walls were prepared in parallel with tooth preparation. The clinically recommended angle of preparation for a complete crown is between 4 and 14 degrees, considering the retention of restoration and convenience of simultaneous insertion. In the present study, we constructed three FE models, representing endocrown-restored molars with respective abduction angles of 0, 6, and 12 degrees. The results showed no obvious differences in stress distributions in either cervical dentin or cement layers among the restored molars. Consistent with these findings, Corazza *et al.* previously reported no differences in fracture resistance among teeth restored with complete crowns with various inclined angles[28].

In this study, we used FE analysis to examine the effect of central retainer shape and abduction angle during tooth preparation on stress distribution in cervical dentin and cement layers in endocrown-restored mandibular molars. In the process of modeling, we assumed perfect adhesion among endocrown and dental hard tissues, which cannot be achieved in the clinic. Moreover, the adhesiveness of restorations is affected by various factors, such as the type and thickness of luting cements, as well as complicated interactions between luting cements and microorganisms in the acidic environment, which are not considered in the study. Adhesive failure in the cement layer is more likely to occur in the oral environment, as the fatigue strength is lower than its ultimate strength. However, the present study only analyzed the stress distribution in the endocrown-restored mandibular molars under static load. Further *in vitro* experiments under fatigue load are necessary.

## CONCLUSION

Within the limitations of this study, our results indicated that, when endocrowns are chosen to restore endodontically treated mandibular molars, central retainer shape should be designed based on the anatomical form of the pulp chamber; moreover, from a mechanical perspective, the abduction angle during tooth preparation would not influence the repair effect of endocrown-restored mandibular molars.

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