Influence of Apical Root Resection on the Biomechanical Response of a Single-rooted Tooth: A 3-dimensional Finite Element Analysis

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Abstract

Introduction: Apical root resection is a biologically essential component in endodontic microsurgery. However, because it reduces the total root length and supported root surface, it changes the biomechanical response of the tooth. The purpose of this study was to analyze the biomechanical effect of apical root resection and to compare apical root resection with periodontal bone loss from a biomechanical standpoint. **Methods:** Finite element models of the maxillary central incisor were reconstructed. First, preoperative and surgically treated models were generated to assess the factors altering the biomechanical response of the tooth. Then, apically resected models with different amounts of resection (3, 4, 5, 6, 7, and 8 mm) were created to estimate the clinically applicable limit of apical root resection. Periodontally destructed models with varying degrees of bone loss (0.5, 1, 1.5, 2, and 3 mm) were also created to compare the effect of apical root resection with periodontal bone loss. Stress distribution, tooth displacement, and effective crown-to-root ratio (α) were analyzed for each condition. **Results:** Apical root resection did not significantly alter the maximum von Mises stress or tooth displacement until it reached 6 mm (α = 0.67) when the tooth was supported by normal periodontium. In contrast, periodontal bone loss had a greater impact on biomechanical response change compared with apical root resection. **Conclusions:** For a tooth supported by normal periodontium, 3 mm of apical root resection (α = 1.07) appeared to be mechanically acceptable. The biomechanical influence of apical root resection was weak compared with that of periodontal bone loss. *(J Endod 2014;40:1489–1493)*

Key Words

Alveolar bone loss, apicoectomy, biomechanics, crown-to-root ratio, endodontic microsurgery, finite element analysis

Apical root resection is one of the most essential components in endodontic microsurgery because it removes the majority of anatomic variations located at the apical one third of the tooth (1–4). The procedure also allows for the repair of mistakes from previous endodontic treatment including apical transportation and endodontic perforation. With this method, apical root resection provides biologically favorable conditions for periapical healing (4, 5).

However, because apical root resection reduces the total root length and supported root surface, it alters the biomechanical response of the tooth, which may result in unfavorable stress distribution and increased tooth mobility (6). Therefore, it is important to assess apical root resection not only in the biological aspect but also in the biomechanical aspect in order to ensure the long-term prognosis of endodontic microsurgery.

The crown-to-root ratio (CRR) has been 1 of the primary variables for the biomechanical evaluation of fixed partial denture abutments (7). Generally, a 1:1.5 CRR is suggested as the optimal value, with a 1:1 CRR as the minimum value for fixed partial denture abutments (8). However, it is unreasonable to directly apply such a guideline to an apically resected tooth because the value is based on investigations of normal or periodontally damaged teeth, not apically resected teeth (9, 10). When considering the fact that apically resected teeth have different properties compared with periodontally damaged teeth in terms of supported root surface and stress distribution (11), the influence of apical root resection should be assessed in a different manner. More qualitative methods are necessary to properly compare the different natures of apical root resection and periodontal bone loss.

The purpose of this study was to assess the biomechanical effect of apical root resection in endodontic microsurgery and to compare apical root resection with periodontal bone loss from a biomechanical standpoint using 3-dimensional finite element analysis. The following hypotheses were tested: (1) apical root resection does not alter the biomechanical response of a single-rooted tooth, and (2) the same amount of apical root resection and periodontal bone loss induce the same degree of biomechanical change of a single-rooted tooth.

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Materials and Methods

Development of Finite Element Models

A 3-dimensional geometric model was reconstructed from cone-beam computed tomographic images of an intact human maxillary central incisor and surrounding bone structures using modeling software (Mimics 14.1; Materialise, Leuven, Belgium; Unigraphics NX 7.0, Siemens PLM Software, Torrance, CA). The total length of the tooth was 21 mm, with 9 mm of crown length and 12 mm of root length. The alveolar bone crest was located 1 mm below the cementoenamel junction, supporting 11 mm of the root. The periodontal ligament was simulated with 200-μm thickness (12). This basic geometric model was modified according to the test conditions and then meshed by linear tetrahedron (C3D4) elements in finite element analysis software (ABAQUS 6.10; SIMULIA, Providence, RI).

Model Group 1

Four different models were developed following the course of treatment to assess the influence of predisposing factors and in-treatment factors on the biomechanical response of the tooth (Fig. 1*A–D*). The basic model was used as an intact model. From the intact model (Fig. 1*A*), an apical periodontitis model (Fig. 1*B*) was generated, simulating bone resorption with a 6-mm diameter around the root apex. Subsequent root canal treatment and apical root resection were simulated in the surgically treated model (Fig. 1*C*). Round root canal enlargement (master apical file #50, 0.06 taper), gutta-percha obturation, and resin core restoration were performed, and a 3-mm apical root resection without a bevel angle, retropreparation (cylinder shaped cavity with a 1.5-mm diameter and 3-mm depth), and MTA retrofilling were conducted on the surgically treated model. The completely healed model (Fig. 1*D*) simulated complete resolution of the periapical bone lesion after surgical intervention, with recovery of the inner cortical bone (0.5-mm thick) and periodontal ligament layer.

Model Group 2

From the completely healed model (Fig. 1*D*), 5 more models were developed with different apical root resection lengths (4, 5, 6, 7, and 8 mm). After including the intact model and completely healed models (Fig. 1*A* and *D*), a total of 7 models were classified into model group 2 to assess the effect of amount of apical root resection. Complete resolution of the periapical lesion was supposed for this group (Fig. 2*A*).

Model Group 3

From the intact model (Fig. 1*A*), 5 more models with different periodontal bone loss amounts (0.5, 1, 1.5, 2, and 3 mm) were developed. After including the intact model (Fig. 1*A*), a total of 6 models were classified as model group 3 to compare the effect of apical root resection with that of periodontal bone loss (Fig. 2*B*).

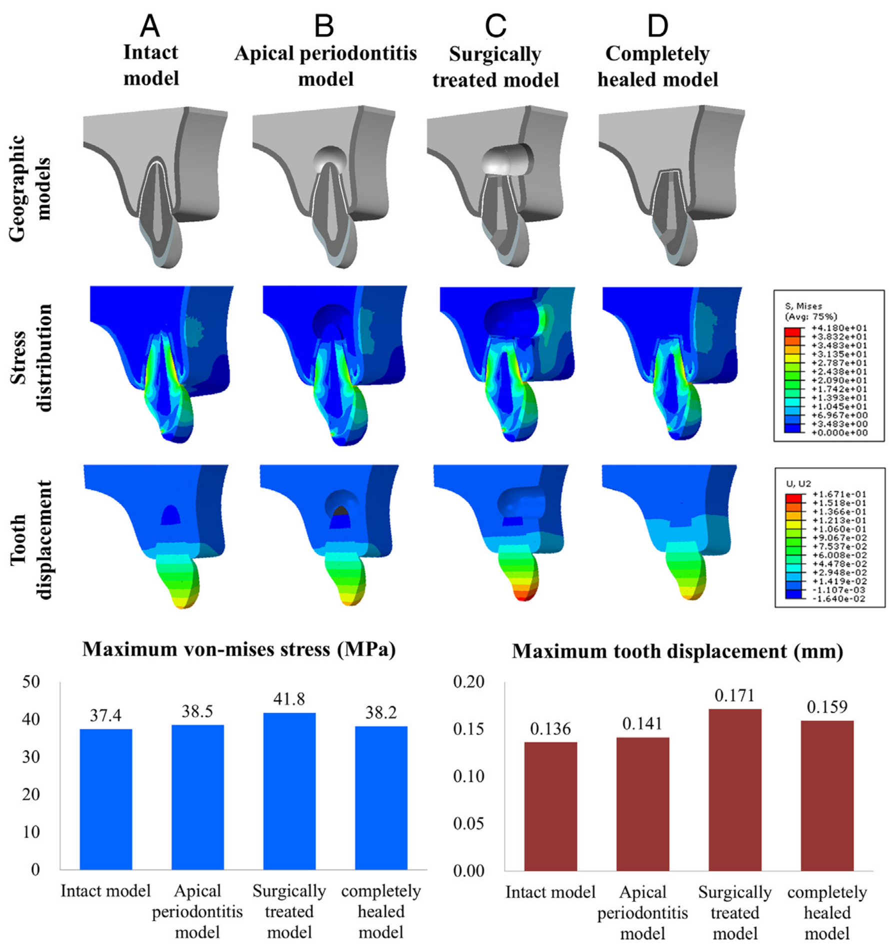

Figure 1. Stress distribution and tooth displacement pattern of models following the course of treatment: (*A*) intact model, (*B*) apical periodontitis model, (*C*) surgically treated model, and (*D*) completely healed model.

Definition of Effective CRR (α)

For people with normal occlusion, the occlusal loading point is located on the lingual surface of the maxillary incisor, not on the incisal edge. Therefore, the modified parameter of the effective CRR was newly defined from traditional CRR considering the anterior overbite, which was reported as 2.5 mm (13). Effective CRR (α) was calculated as follows:

$$\text{Effective CRR} = \text{Clinical Root Length} / (\text{Clinical Crown Length} - 2.5\ \text{mm})$$

where clinical root length = 11 mm − amount of apical resection or periodontal bone loss and clinical crown Length = 10 mm + amount of periodontal bone loss.

Finite Element Analysis

Homogenous, isotropic, and linear elastic properties were assumed for all the tissues and materials, as were perfect bonded conditions. Table 1 shows the applied material properties obtained from literature surveys (14–18). The models were constrained at the upper base of the supporting bone structure. A static 100-N load was applied to the palatal surface of the crown at a 45° angle from the longitudinal axis of the tooth (17, 19). Stress distribution and tooth displacement pattern were calculated using ABAQUS 6.10. The maximum von Mises stress (σ max) and maximum tooth displacement (ΔR max) values were then measured for each model.

Results

Model Group 1

Periapical bone resorption and nonsurgical and surgical endodontic treatments increased the values of σ max and ΔR max. Nonsurgical and surgical endodontic treatment including apical root resection had the greatest influence on the parameters, increasing σ max by 8.6% and ΔR max by 21.3% compared with the apical periodontitis model (Fig. 1).

On the other hand, periapical bone healing decreased the σ max and ΔR max values (Fig. 1). It considerably improved the parameters after surgical endodontic treatment, showing an 8.6% reduction of σ max and a 7.0% reduction of ΔR max between the completely healed model (Fig. 1*D*) and surgically treated model (Fig. 1*C*).

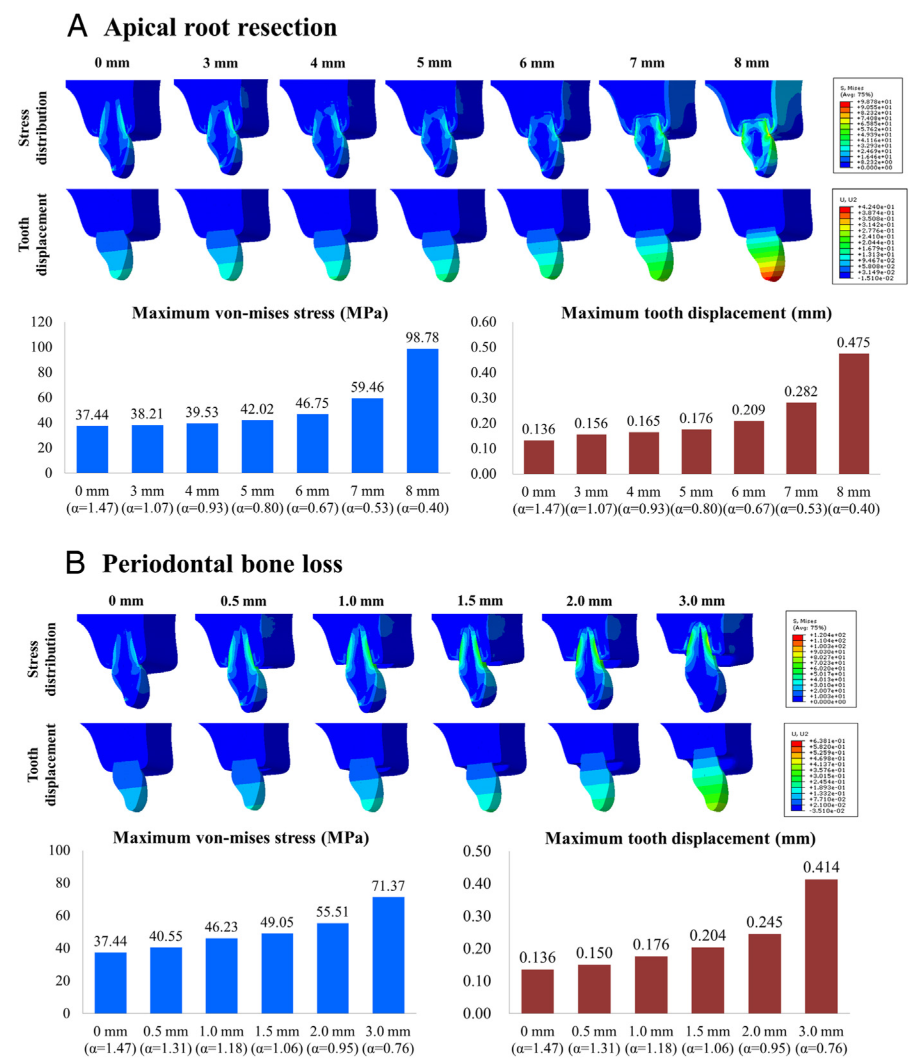

Figure 2. (*A*) Stress distribution and tooth displacement pattern of the intact model and models receiving 3, 4, 5, 6, 7, and 8 mm of apical root resection and (*B*) models receiving 0.5, 1, 1.5, 2, and 3 mm of periodontal bone loss.

TABLE 1. Material Properties

Material	Elastic modulus (GPa)	Poisson ratio	References
Dentin	18.6	0.31	17
Enamel	41	0.30	14
Periodontal ligament	0.05	0.49	18
Cortical bone	13.7	0.30	17
Trabecular bone	1.37	0.30	17
Pulp	0.00207	0.45	14
Gutta-percha	0.00069	0.45	17
Composite resin	12	0.33	15
MTA (Portland cement)	22.4	0.25	16

GPa, gigapascal; MTA, mineral trioxide aggregate.

Model Groups 2 and 3

Periodontal bone loss strongly influenced both σ max and ΔR max compared with the same amount of apical root resection. When 3 mm of apical root resection was performed, the σ max value increased by 2.1% and the ΔR max value increased by 14.7% compared with the preoperative status. On the other hand, when 3 mm of periodontal bone loss was indicated, the σ max value increased by 90.6% and the ΔR max value increased by 204.4% compared with the preoperative status (Fig. 2).

In addition, a greater amount of apical root resection was required to induce the similar degree of biomechanical change compared with periodontal bone loss. In this study, 1 mm of marginal bone loss (α = 1.18) resulted in higher σ max and ΔR max values compared with 4 mm of apical root resection (α = 0.93) (Fig. 2). Also, 2 mm of marginal bone loss (α = 0.95) resulted in greater σ max and ΔR max values compared with 6 mm of apical root resection (α = 0. 67) (Fig. 2).

When arranged by effective CRR, a similar trend was identified. Periodontal bone loss influenced both σ max and ΔR max earlier and revealed a more increased rate compared with apical root resection (Fig. 3).

Discussion

As teeth experience pathologic change and subsequent endodontic treatments, dentoalveolar structures are continuously modified. This study simulated major events such as periapical bone resorption, nonsurgical and surgical endodontic treatment, and periapical bone healing. As a result, it was confirmed that all of these events affect the biomechanical response of a tooth, rejecting the first null hypothesis (Fig. 1).

As expected, surgical treatment including apical root resection was the main event that increased the σ max and ΔR max values. However, the parameters improved after periapical bone healing, resulting in a slightly increased ΔR max (12.8%) and a reduction in σ max (0.8%) compared with the apical periodontitis model (Fig. 1). This result indicates that increased mobility after endodontic microsurgery could be reduced as the periapical bone is regenerated. Therefore, adequate periapical healing is an essential component in endodontic microsurgery not only for endodontic success but also for biomechanical re-establishment.

We then compared apical root resection with periodontal bone loss from a biomechanical standpoint. Interestingly, the influence of apical root resection on the biomechanical parameters was not significant compared with that of periodontal bone loss. Apical root resection in a tooth supported by normal periodontium did not significantly affect the biomechanical parameters until it reached 6 mm (α = 0.67) (Fig. 2A). However, periodontal bone loss more strongly influenced the same parameters, showing an even worse response compared with 6 mm of apical root resection at 2 mm of periodontal bone loss (Fig. 2). Consequently, the second null hypothesis was also rejected.

The cause of this difference remains to be determined. One explanation could be that periodontal bone loss rapidly worsens CRR by simultaneously increasing clinical crown length and decreasing supported root length compared with apical root resection, which reduces only root length. However, Figure 3 clearly reveals that periodontal bone loss more sensitively influences biomechanical parameters than apical root resection, even under the supposition of the same effective CRR. In other words, the deterioration of CRR induced by apical root resection more weakly influenced the biomechanical parameters compared with that of periodontal bone loss.

Another explanation could be the 2 different natures of the apical and coronal thirds of the root, the supported root surface and stress distribution. Supported root surface is reported to be 8 times wider in the coronal 3 mm compared with the apical 3 mm of a root (11). Such an anatomic difference could result in relatively less reduction of bone support by apical resection compared with periodontal bone loss. In addition, it should be noted that most of the stress from occlusal loading is concentrated on the cervical one third of the root, not the apical one third. Consequently, bone support loss in the apical region by apical resection could less sensitively influence the stress distribution of the root compared with that of the cervical region by periodontal bone loss (11, 20).

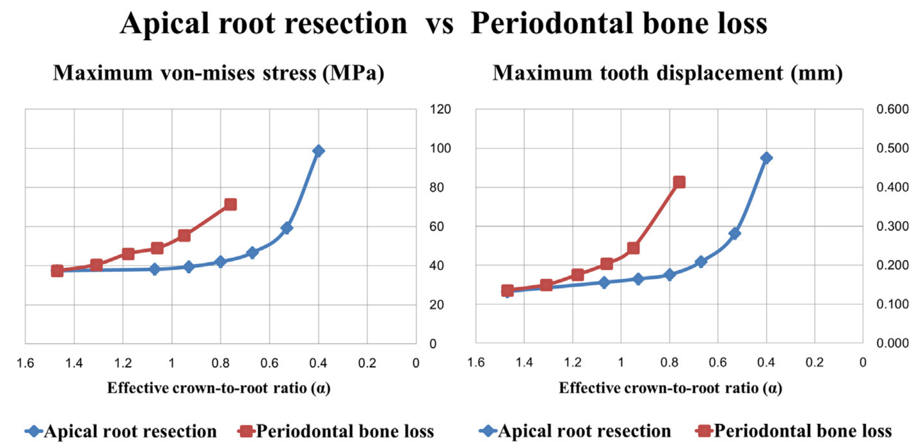

Figure 3. Maximum von Mises stress and maximum tooth displacement of the apically resected and periodontally damaged models arranged by effective CRR (α).

Therefore, it is unreasonable to estimate the biomechanical effect of apical root resection based on previous prosthodontic literature, which mostly investigated periodontally damaged teeth. Although CRR could be used as a useful parameter of abutment evaluation, an apically resected tooth should be assessed in a different manner.

In this study, 3 mm of apical root resection ($\alpha = 1.07$) appeared to be mechanically acceptable for a tooth supported by normal periodontium. More than 3 mm of resection is possible for cases with large endodontic perforation or anatomic variations, but CRR and occlusal loading conditions must be considered. However, more than 6 mm of resection ($\alpha < 0.67$) should be carefully considered because it could result in unfavorable stress distribution and increased tooth mobility.

Stress distribution and tooth displacement were used as representative biomechanical parameters in this study. The evaluation of stress distribution is 1 of the key elements for abutment evaluation because teeth are under constant occlusal loading. Vertical root fracture has been reported as the main reason for extraction after endodontic microsurgery (21). Therefore, stress distribution must be considered before treatment to prevent excess stress concentration on root dentin. For this reason, we adopted the von Mises criterion to represent the stress level in this study. Because von Mises stress can be directly compared with the yield strength of the material, it has been regarded as an effective indicator in predicting stress concentration and subsequent failure occurrence in dentin (22, 23). Tooth displacement was analyzed to reproduce clinical tooth mobility. Tooth mobility is not only an important parameter in evaluating alveolar bone support but also an important requirement that should be controlled in the normal range to maintain masticatory function.

This study analyzed an average maxillary central incisor of the Asian population, which was reported to be approximately 22 mm in length (24). However, because root length varies based on individual and ethnic group (24), apical root resection amount cannot be uniformly recommended. Therefore, effective CRR was calculated for each model to provide an expandable guideline for clinical situations.

Endodontic microsurgery is an effective way to treat apical pathosis, which cannot be controlled by nonsurgical root canal treatment. Because the success rate and long-term prognosis of endodontic microsurgery have been validated, the process is becoming a standard treatment option in the endodontic field (25–30). However, because it alters the stress distribution and mobility of the tooth, biomechanical consideration should precede endodontic microsurgery. Also, the amount of apical root resection should be determined based on both biologic and biomechanical standpoints. Further clinical and *in vitro* studies are necessary to more clearly show the effect of apical root resection and to supplement the limitations of this numerical analysis study.

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Youngjune Jang and Hyoung-Taek Hong contributed equally to this study as first author.

Byoung-Duck Roh and Heoung-Jae Chun contributed equally to this study as corresponding author.

The authors deny any conflicts of interest related to this study.

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