# Influence of Apical Root Resection on the Biomechanical Response of a Single-rooted Tooth—Part 2: Apical Root Resection Combined with Periodontal Bone Loss

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## Abstract

**Introduction:** In a clinical situation, an apically resected tooth is often accompanied by a varying degree of periodontal bone loss. The purpose of this study was to assess the influence of apical root resection combined with periodontal bone loss on the biomechanical response of a single-rooted tooth. **Methods:** A basic intact model and a basic apically resected model of the upper central incisor were selected for the numerical analysis. From each basic model, 6 models were developed assuming different amounts of periodontal bone loss (0, 0.5, 1, 1.5, 2, and 3 mm). Maximum von Mises stress ($\sigma$ max), maximum tooth displacement ($\Delta R$ max), and effective crown-to-root ratio ($\alpha$) were calculated for each condition. **Results:** There were only marginal differences (a 2.1% difference in $\sigma$ max and a 16.9% difference in $\Delta R$ max) between the biomechanical responses of the intact model and the apically resected model when the tooth was supported by a normal periodontium. However, when destruction of the periodontium was assumed, the intact model and the apically resected model responded differently. The difference increased as the periodontal bone loss progressed, resulting in a 68.7% difference in $\sigma$ max and a 56.3% difference in $\Delta R$ max when the periodontal bone loss increased to 3 mm ($\alpha$ = 0.48). **Conclusions:** Although the biomechanical response of an apically resected tooth was relatively stable when the tooth was supported by a normal periodontium, the apically resected tooth showed a more deteriorated response compared with the intact tooth as the periodontal bone loss progressed. *(J Endod 2015;41:412–416)*

## Key Words

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

Up until now, the success of endodontic microsurgery has been characterized by biologic recovery, mainly based on healing of the periapical lesion (1–12). However, it should be noted that an apically resected tooth would be exposed to continuous occlusal loading even after complete biologic recovery. Therefore, to ensure good long-term prognosis of an apically resected tooth, it is important to provide favorable biomechanical conditions (13). In this context, several attempts have been made to assess the influence of biomechanical factors associated with an apically resected tooth (14, 15), and recently, Jang et al (16) suggested that 3 mm of apical root resection does not induce a significant change in the biomechanical parameters when the tooth is supported by a normal periodontium.

However, in a clinical situation, teeth often undergo not only apical root resection but also experience varying extents of periodontal bone loss at the same time. For example, an apically resected tooth could be affected by periodontal disease that accompanies surrounding alveolar bone loss, or a tooth already affected by periodontal disease could undergo endodontic surgery including apical root resection (2, 4–6). Therefore, there is a need to simulate both apical root resection and periodontal bone destruction in the same model to provide a better prediction about the prognosis of an apically resected tooth from a biomechanical standpoint.

The purpose of this study was to evaluate the influence of apical root resection on the biomechanical response of a single-rooted tooth under varying degrees of periodontal bone loss, by comparing an intact tooth and an apically resected tooth using 3-dimensional finite element analysis (FEA). The null hypothesis for this study was that an apically resected tooth and an intact tooth show the same degree of biomechanical changes with the same amount of periodontal bone loss.

## Materials and Methods

### Development of Geometric Models

Two 3-dimensional geometric models of an upper incisor reconstructed in the preceding study (16) were selected as the basic models in this study for the continuity of data analysis. From these models, a total of 12 different models with varying degrees of periodontal bone loss were developed.

### Model Group 1 (Intact Models)

For developing the models in this group, the "intact model" from the preceding study (16) was used as the basic intact model (Fig. 1). The total length of the model was 21 mm, which included 12 mm of the anatomic root and 9 mm of the anatomic

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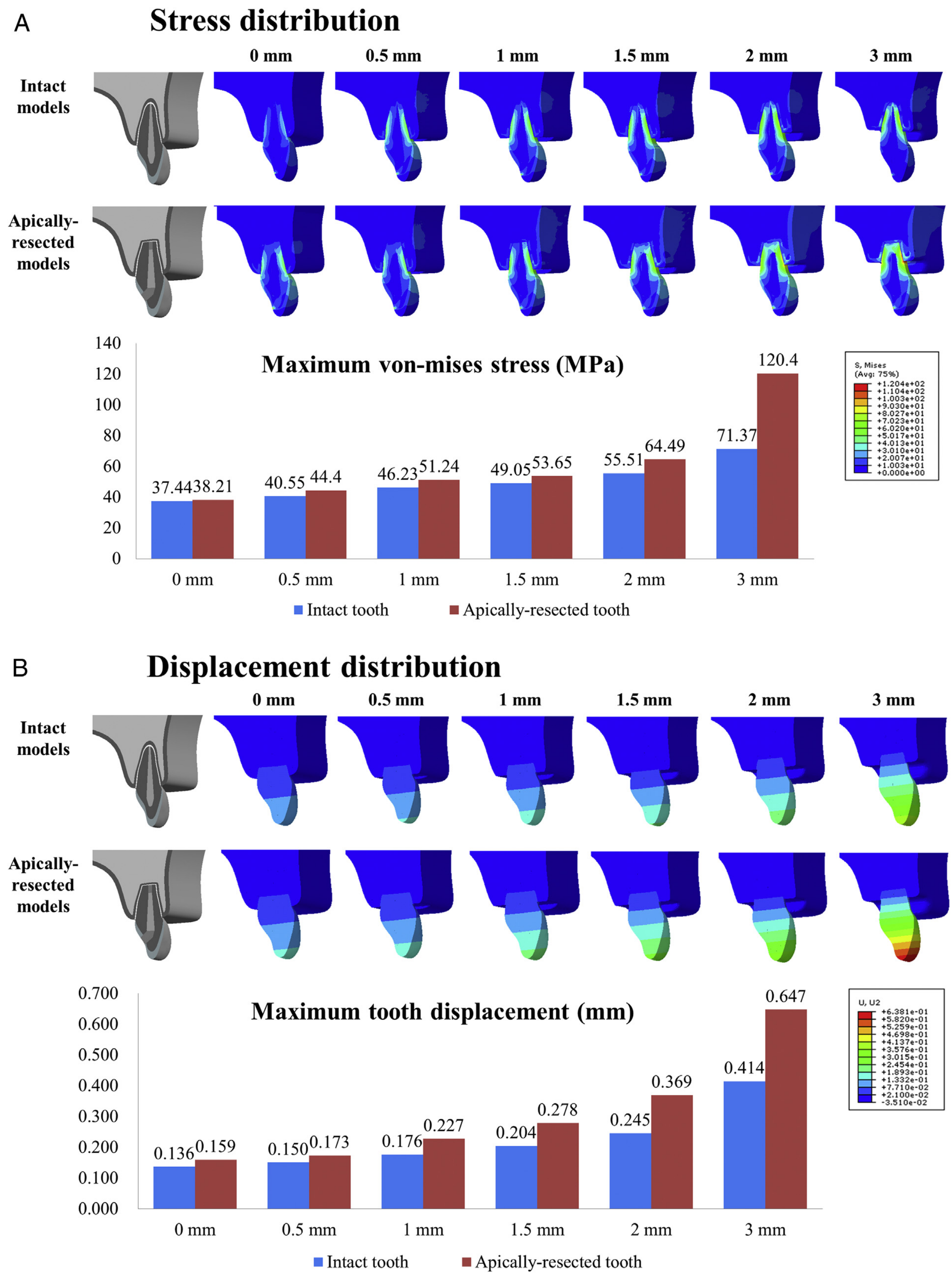


**Figure 1.** (*A*) Stress distribution in the intact model and the apically resected model with 0, 0.5, 1, 1.5, 2, and 3 mm of periodontal bone loss, and (*B*) displacement distribution in the intact model and the apically resected model with 0, 0.5, 1, 1.5, 2, and 3 mm of periodontal bone loss. (The FEA result of "model group 1" and the "basic apically resected model" was identical with the result of "model group 3" and the "completely healed model" of the preceding study [16] because the same geographic structure and material properties were assumed between these models.)

crown. The lower 11 mm of the root was supported by the surrounding bone structures because the marginal bone crest was positioned 1 mm below the cementoenamel junction. Constant thickness of the periodontal ligament layer (200 $\mu$m) was assumed between the root and alveolar bone structures (17). From this basic intact model, 5 more models were developed assuming different amounts of periodontal bone loss (0.5, 1, 1.5, 2, and 3 mm in the vertical direction). Including the basic intact model (with 0 mm of periodontal bone loss), a total of 6 models were categorized into model group 1 (Fig. 1).

### Model Group 2 (Apically Resected Models)

For developing the models in this group, the "completely healed model" from the preceding study (16) was used as the basic apically resected model (Fig. 1). This was the model that reproduced routine nonsurgical and surgical endodontic treatment by undergoing round canal shaping (.06 taper), gutta-percha filling, resin core filling, apical root resection (3 mm, without bevel), root-end preparation (cylindric cavity with 3-mm depth), and root-end filling with MTA. Complete healing of the periapical lesion and surgical access cavity was assumed in this model. From this basic apically resected model, 5 more models were developed assuming different amounts of periodontal bone loss (0.5, 1, 1.5, 2, and 3 mm in the vertical direction). Including the basic apically resected model (with 0 mm of periodontal bone loss), a total of 6 models were categorized into model group 2 (Fig. 1).

### Definition of Effective Crown-to-root Ratio ($\alpha$)

An effective crown-to-root ratio (CRR) was determined by using the following formula: effective CRR = clinical root length/(clinical crown length − 2.5 mm), where clinical root length = 11 mm – the amount of apical resection or periodontal bone loss and clinical crown length = 10 mm + amount of periodontal bone loss (16).

### Development of Finite Element Models

These geometric models were then imported into FEA software (ABAQUS 6.10; Simulia, Providence, RI) for conversion to finite element models. Meshing of each model was performed with linear tetrahedron (C3D4) elements. All tissues and materials were assumed to be isotropic, homogeneous, and linear elastic, and a perfect bonding condition was assumed among all of the components. Material properties, which were equivalent with those in the preceding study (16), were applied for correlation between the FEA data of both studies.

### Finite Element Analysis

Constant loading (100 N) was applied to the lingual surface of the crown in an oblique direction (45°) from the long axis of the model (18). Stress distribution and displacement distribution were evaluated, and the maximum von Mises stress ($\sigma$ max) and maximum tooth displacement ($\Delta$R max) values were calculated for each model using ABAQUS 6.10.

## Results

In this study, the FEA result of "model group 1" and the "basic apically resected model" was identical with the result of "model group 3" and the "completely healed model" of the preceding study (16), which is because the same geographic structure and material properties were applied between these models.

### Stress Distribution

Periodontal bone loss more strongly influenced the $\sigma$ max value of model group 2 compared with that of model group 1, and the difference in $\sigma$ max between the 2 groups increased as the periodontal bone loss progressed (Fig. 2*A*). When the periodontal bone loss was absent or the amount of periodontal bone loss was 2 mm or less, the intact model and the apically resected model showed similar $\sigma$ max (the difference ranged between 2.1% and 16.2%). However, when the amount of periodontal bone loss increased to 3 mm, the difference in $\sigma$ max steeply increased to 68.7% (Fig. 1*A*). When arranged according to the effective CRR, the apically resected models were in the upper left–shifted position compared with the intact models, showing decreased effective CRR and increased $\sigma$ max values (Fig. 2*B*). The location of the $\sigma$ max point was also different between model groups 1 and 2. In model group 1, the $\sigma$ max point was located on the middle one third of the root, whereas it was located around the alveolar bone crest in the model group 2 (Fig. 1*A*).

### Displacement Distribution

As in the case of stress distribution, periodontal bone loss more strongly influenced the $\Delta$R max value of model group 2 compared with that of model group 1, and the difference in $\Delta$R max between the 2 groups increased as the periodontal bone loss progressed (Fig. 2*A*). When the periodontal bone loss was absent or the amount of periodontal bone loss was 0.5 mm or less, the difference in $\Delta$R max between model groups 1 and 2 ranged between 15.3% and 16.9%. However, the difference in $\Delta$R max between model groups 1 and 2 began to increase since then, and the difference in $\Delta$R max reached 56.3% as the amount of periodontal bone loss increased to 3 mm (Fig. 1*B*). When arranged according to the effective CRR, the apically resected models were in the upper left–shifted position compared with the intact models, showing decreased effective CRR and increased $\Delta$R max values (Fig. 2*B*).

## Discussion

There were only marginal differences (a 2.1% difference in $\sigma$ max and a 16.9% difference in $\Delta$R max) between the biomechanical responses of the intact tooth and the apically resected tooth when the tooth was supported by a normal periodontium (Fig. 1), which is consistent with the findings of Jang et al (16). However, when destruction of the supporting periodontium was supposed, the intact tooth and the apically resected tooth responded differently, and the difference in biomechanical parameters increased as the amount of periodontal bone loss increased (Fig. 2*A*). In other words, the apically resected tooth responded more sensitively compared with the intact tooth at the same amount of periodontal bone loss, rejecting the null hypothesis.

The causes of this discrepancy remain to be explained. Basically, it should be noted that the CRR deteriorated more rapidly in the apically resected tooth compared with the intact tooth as the periodontal bone loss progressed (Fig. 3). When considering that the effective CRR is inversely related to the biomechanical parameters ($\sigma$ max and $\Delta$R max) (16), rapid deterioration of the effective CRR in the apically resected tooth could be the primary factor that caused the discrepancy in biomechanical responses between the 2 groups.

Another explanation is possible based on the tooth avulsion model of Miura and Maeda (19). They reported that when the stress level in the periodontal ligament space exceeds a certain threshold by an external force, the tooth begins to rotate with the alveolar ridge as the center, and stress concentration occurs on the alveolar bone crest and adjacent root dentin (19). As already known, because apical root resection reduces the distance between the root apex and the alveolar ridge crest, the length of the effort arm is always shorter in the apically resected tooth than in the intact tooth with the same periodontal condition.

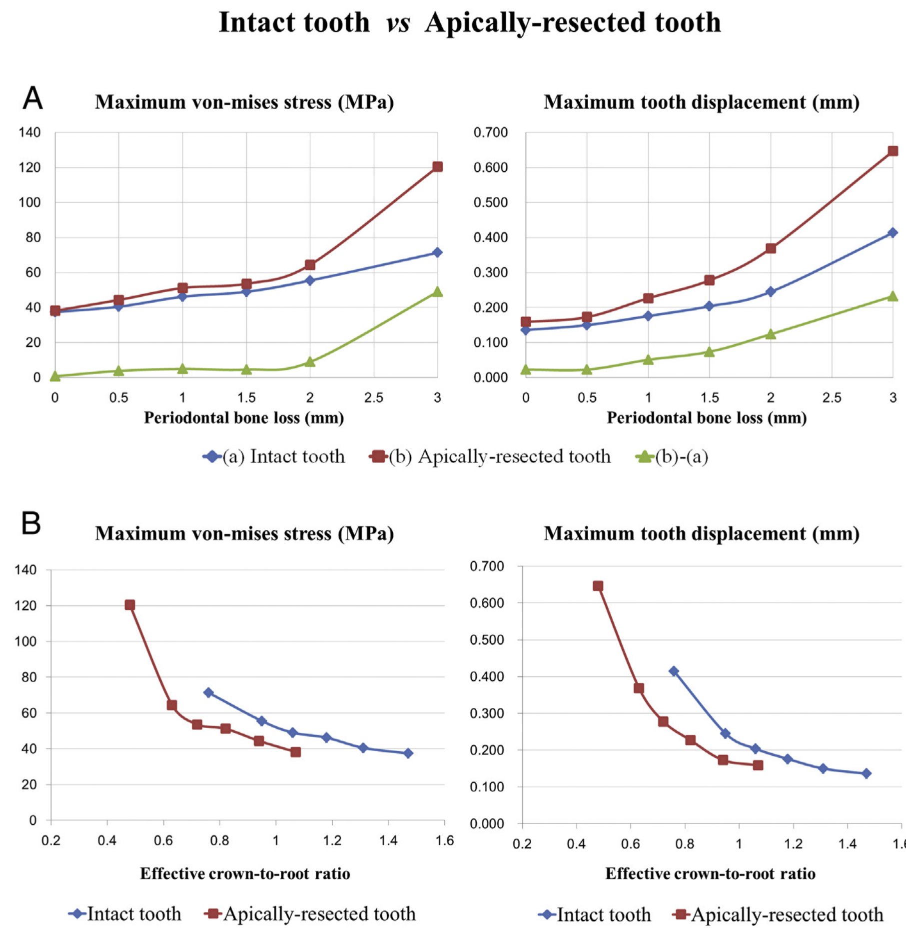


**Figure 2.** Maximum von Mises stress and maximum tooth displacement in the intact and apically resected models arranged according to (*A*) the amount of periodontal bone loss and (*B*) effective CRR ($\alpha$).

Therefore, apical root resection could cause additional stress in the periodontal ligament space of the treated tooth, inducing the apically resected tooth to experience additional rotational displacement and stress concentration at a relatively low degree of periodontal bone loss. Actually, in this study, the $\sigma$ max and $\Delta$R max were considerably increased in the apically resected tooth compared with the intact tooth (Fig. 2*A*), and the $\sigma$ max point was located on the root dentin adjacent to the buccal bone crest, especially when the periodontal bone loss exceeded 2 mm (Fig. 1*A*).

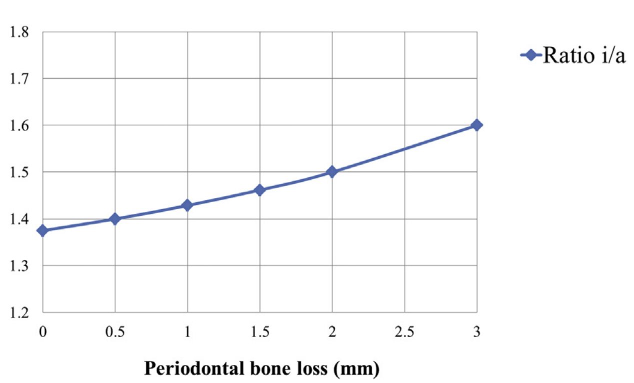


**Figure 3.** The ratio between effective CRRs of the intact and apically resected models (ratio i/a) arranged according to the amount of periodontal bone loss, which was calculated by using the following equation: ratio i/a = effective CRR of the intact model/effective CRR of the apically resected model.

Because the apically resected tooth showed a worse biomechanical response compared with the intact tooth under periodontal bone loss, clinicians should pay more attention to the periodontal condition of the tooth before and after endodontic surgery, which includes apical root resection. From the start of treatment planning, the appropriateness of apical root resection should be evaluated based on the periodontal condition. To assist in the clinical decision-making process, the effective CRR of each model was calculated and presented with biomechanical parameters (Fig. 2*B*), improving the availability of the data on various clinical cases. The importance of periodontal maintenance care should also be emphasized after endodontic microsurgery to minimize the loss of supporting bone structures. In the same vein, special attention should be paid during intentional replantation when considering that marginal bone loss often occurs after surgical repositioning of the tooth (20–22). The tooth and the surrounding bone structures should be treated atraumatically as much as possible during extraction and surgical repositioning of the tooth to reduce the postoperative marginal bone loss. According to the results of this study, it appears that the amount of total periodontal bone loss should not exceed 2 mm ($\alpha > 0.63$) with the apically resected tooth to prevent possible adverse effects on the clinical prognosis.

In this study, 2 representative biomechanical factors, the amount of periodontal bone loss and apical root resection, were simulated simultaneously to optimize the model. As a result, we could determine the differences between the behaviors of the intact tooth and the apically resected tooth, which were not identified in the preceding study (16).

However, it should be noted that this is only the beginning of model optimization, and there are other possible clinical variables that need to be considered together, such as splinting with adjacent teeth and a reduced amount of apical root resection (less than 3 mm). Splinting of teeth is one of the alternative treatments of choice in teeth revealing excessive mobility from periodontal destruction (23) because it promotes the distribution of occlusal loading into the connected teeth. A reduction in the amount of apical root resection is another considerable treatment option to prevent significant deterioration of CRR in teeth exposed to extensive periodontal bone loss. However, because these variables considerably increase the number or complexity of the models, they were not reproduced in our models, which are the limitations of this study. Therefore, further studies with improved models are needed to more precisely predict the biomechanical behavior of an apically resected tooth. Clinical trials would also be needed to confirm the clinical relevance of these findings, thus complementing the limitation of this numeric analytic study.

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*Youngjune Jang and Hyoung-Taek Hong contributed equally to this work as first authors. Byoung-Duck Roh and Heoung-Jae Chun contributed equally to this work as corresponding authors.*

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

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