Finite element analysis of the stress variations on the root canal wall of pulpless tooth by different root canal preparations

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Purpose: To analyze the stress variations of the root canal wall of pulpless tooth by different root canal preparations (RCPs).

Materials and Methods: A finite element model was set up for the mandibular first molar with standard root shape and treated as control. Routine root canal preparation (R-RCP) and root canal preparation by step-back technique (RCP-SBT) were modeled. The study was performed under the loading at the top of the molar occlusal rest in vertical and oblique 45-degree orientations. The maximum von Mises stresses were calculated in each part of the tooth, the wall of mesial-buccal, mesial-lingual, and distal root canal.

Results: Compared with the control model, R-RCP model and RCP-SBT model showed that the maximum von Mises stress have no significant changes in each part of the tooth except in the amalgam layer, which became a little larger. There are also no larger changes on the wall of mesial-buccal, mesial-lingual, and distal root canal.

Conclusion: R-RCP and RCP-SBT will not affect greatly the root and dentin in biomechanics.

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Clinical Significance: The results of the current study demonstrate that R-RCP and RCP-SBT are satisfied techniques for tooth.

Key Words: finite element analysis, root canal preparation, step-back technique.

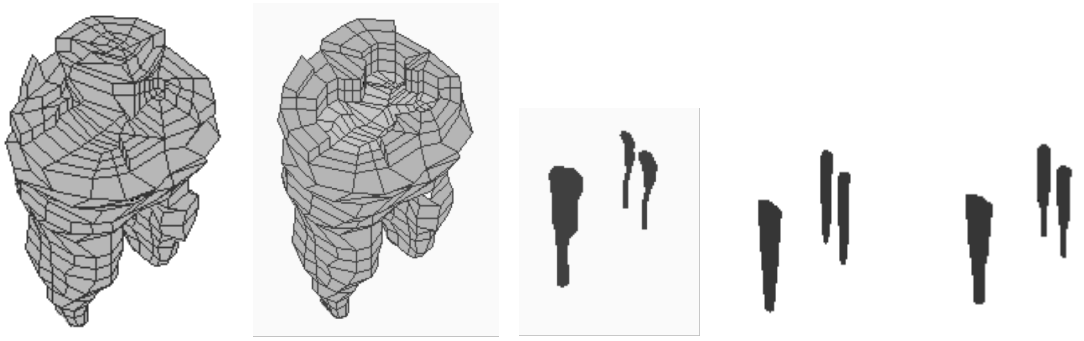
Introduction

Routine root canal preparation (R-RCP) and root canal preparation by step-back technique (RCP-SBT) are often used in dental clinic treatment.[1,2] However, their effects to the dentin were not reported yet. Finite element analysis (FEA)[3,4] is, therefore, utilized in this work as an important tool to evaluate these effects and the dentin and root canal biomechanical characteristics of different RCPs.

Materials and Methods

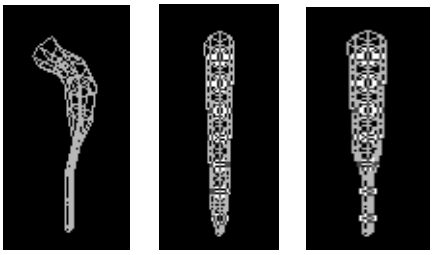
A first molar of mandible was modeled using FEA, 3-D mesh by Super-SAP 6.0 (Fig. 1). It had the

standard root shape and was treated as the control. The mesial root canal is round-shaped and the distal root canal is oval-shaped. Marrow cavity was filled with zinc phosphate cement. The molar occlusal center part was filled with amalgam layer. R-RCP and RCP-SBT were modeled as the shape in Figs. 2 and 3. Root canals were filled with gutta-percha.



1 1 2a 2b 2c

Fig. 1. The three dimensional finite-element model of the mandibular first molar.
Fig. 2. Root canal appearances of three models; (a) original model, (b) routine root canal preparation, and (c) root canal preparation by step-back technique.



a b c

Fig. 3.
Three root canal appearances of mesial-buccal root canal; (a) original model, (b) routine root canal preparation, and (c) root canal preparation by step-back technique.

Load Conditions and Boundary Conditions

A nodal force (Load) of 100 N is applied on the top of the molar occlusal rest in vertical and oblique 45-degree orientations. The nodes over the free edges of the root part in the mandible were constrained in the x-, y-, and z-directional rigid movement.

Material Properties

The corresponding material properties were shown in Table 1.

Table 1. Material properties.

Material	Young's modulus (MPa)	Poisson's ratio
Enamel	41,400	0.30
Dentin	18,600	0.32
Amalgam layer	13,720	0.33
Zinc phosphate cement	22,400	0.25
Gutta-percha	0.69	0.45

Finite Element Mesh

The finite element model was created using Element Topology: Quad4; and Global edge length: 0.5 mm; but at the interface between the root canal and dentin, Global edge length is about 0.1 mm. Global edge lengths were determined by pilot test.

Table 2. The maximum von Mises stress in different part of the tooth (MPa).

Position	Original model		R-RCP model		RCP-SBT model	
	Vertical load	Oblique load	Vertical load	Oblique load	Vertical load	Oblique load
Amalgam layer (Enamel)	100.92	106.69	131.67	140.91	131.67	140.97
Amalgam layer (Dentin)	40.92	43.46	78.24	78.90	78.24	78.90
Zinc phosphate cement (Marrow cavity top)	26.31	30.50	22.50	28.21	22.50	28.21
Zinc phosphate cement (Marrow cavity)	29.20	49.24	18.54	30.47	18.53	30.47
Zinc phosphate cement (Root canal top)	30.49	50.49	20.19	36.62	22.91	39.24
Root canal top 1/3	12.12	18.24	10.10	13.02	10.20	16.62
Root canal middle 1/3	1.23	1.24	0.92	1.35	1.40	1.53
Root canal bottom 1/3	0.09	0.12	0.05	0.06	0.11	0.13

Table 3. The maximum stress of the wall of mesial-buccal root canal (MPa).

Position	Original model		R-RCP model		RCP-SBT model	
	Vertical load	Oblique load	Vertical load	Oblique load	Vertical load	Oblique load
Root canal top	29.20	43.58	18.19	20.25	17.34	20.82
Root canal top 1/3	12.23	18.24	7.16	10.92	10.20	13.25
Root canal middle 1/3	0.85	0.96	0.30	0.32	1.02	1.03
Root canal bottom 1/3	0.10	0.11	0.07	0.08	0.09	0.11

Table 4. The maximum stress of the wall of mesial-lingual root canal (MPa).

Position	Original model		R-RCP model		RCP-SBT model	
	Vertical load	Oblique load	Vertical load	Oblique load	Vertical load	Oblique load
Root canal top	8.98	10.48	8.34	10.35	8.89	9.78
Root canal top 1/3	10.67	10.60	3.35	5.72	3.17	4.73
Root canal middle 1/3	0.25	0.56	0.34	0.38	0.52	0.63
Root canal bottom 1/3	0.03	0.03	0.02	0.04	0.02	0.05

Table 5. The maximum stress of the wall of distal root canal (MPa).

Position	Original model		R-RCP model		RCP-SBT model	
	Vertical load	Oblique load	Vertical load	Oblique load	Vertical load	Oblique load
Root canal top	17.89	27.15	12.63	16.01	12.23	18.58
Root canal top 1/3	9.15	11.71	6.52	9.22	6.88	9.85
Root canal middle 1/3	0.55	0.61	0.69	0.92	0.69	0.94
Root canal bottom 1/3	0.07	0.09	0.02	0.05	0.02	0.05

Results

The results of maximum von Mises stress distribution in the different part of the tooth and root canals were shown in Tables 2 to 5.

Discussion

Effects of the Loading Directions

The maximum von Mises stress in the wall of root canal is affected by the loading directions. Table 2 shows that, for the vertical load conditions, the absolute stress became lower from the crown part to the root part. However, there is a second maximum stress at the top of root canal. Compared with the control, R-RCP model and RCP-SBT model showed that the maximum von Mises stress have no significant changes in each part of the tooth except in the amalgam layer, which became a little larger. For the oblique load conditions, the stress trend is the similar as the vertical load conditions. The absolute stress became a little higher in the oblique load conditions.

Stress Distribution in the Wall of Root Canals

Table 3 to 5 show that, under vertical and oblique loading conditions, the absolute stress in R-RCP model and RCP-SBT model was lower than that in the control model. The absolute stress became lower from the root canal top to bottom. The absolute stress also became a little higher in the oblique load conditions.

Conclusion

It can be concluded that both R-RCP and RCP-SBT will not affect greatly the root and dentin in biomechanics. It demonstrated that R-RCP and RCP-SBT are satisfied techniques for tooth.

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