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Finite element analysis to study the effects of using CAD/CAM glass-fiber post system in a severely damaged anterior tooth

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Abstract. To investigate the stress distribution of a severely damaged maxillary anterior tooth restored with a computer-aided design/computer-aided manufacturing (CAD/CAM) glass-fiber post system. Twelve models were fabricated with different alveolar bone levels and cervical dentin wall thicknesses and studied using a two-dimensional finite element method. A force of 100 N was applied to the lingual surface of the crown at 45 degrees, and the maximum von Mises stress was calculated. A higher stress level was observed in the dentin than in the post and crown. With the reduction of dentin thickness, the maximum von Mises stress in the dentin increased slightly to a peak at a thickness of 1.5 mm, followed by a slight decrease at a thickness of 1.0 mm. However, the relative ratio (RR) values did not show a large difference (RR > 80%). Meanwhile, a large difference in RR values was observed with a change in bone level (RR < 80%). When using a CAD/CAM glass-fiber post system, the maximal von Mises stress was significantly affected by the bone level, rather than by the dentin thickness. Moreover, this system may be applied to the treatment of a maxillary anterior tooth with a bone level of only 2/3.

Keywords: computer-aided design/computer-aided manufacturing (CAD/CAM) glass-fiber, finite element analysis, post and core

1. Introduction

Major advances in endodontic therapy have significantly altered the practice of dentistry. Teeth that were once considered non-restorable and extracted are now commonly treated endodontically and restored to function. Currently, it is common to place a dowel and core in order to improve the retention of the subsequent crown in cases of unsubstantial tooth structure. It is believed that the dowel plays an important role in strengthening the retention of the tooth. However, structurally compromised teeth are not reinforced by post insertion when subjected to sustained masticatory forces [1]. Several factors that influence the strength of endodontically treated teeth have been discussed. Chieruzzi, et al. found that masticatory loads were strictly related to the bond at the interface of the post/cement and the cement/dentin [2]. The resistance of endodontically treated premolars to fracture is dependent on the number of residual coronal dentin walls [3, 4]. Considering these conditions, it makes restoring the shape of teeth more complicated. Therefore, choosing an appropriate prosthesis is very important for

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Table 1
Mechanical properties of the dental structures and materials used in this study

Material	Elastic modulus (GPa)	Poisson's ratio
Dentin	18.6	0.31
Gutta-percha	0.00069	0.45
Glass-fiber post	20	0.30
Glass-ceramic	62	0.30

the durability of endodontically treated teeth.

Some studies indicate that the elastic modulus of the post is similar to that of the dentin and core, and that it has a better biomechanical performance [5, 6]. Stainless steel posts present a higher level of stress concentration than some other post materials because of their highly elastic modulus [7]. Compared to other post systems, fiber reinforcement posts do not provide any increase in fracture resistance [8]. A large amount of glass-fiber posts and composite resin cores are separated, which may lead to failure of the restoration due to a weak interface [9]. In addition, Bitter, et al. [10] found that nanoleakage may occur at the edge of the crown and destroy the hermetic luting systems in the root. Furthermore, the diameters of glass-fiber posts are not completely adaptive to the prepared space. A clinical report [11] has shown that a glass-fiber post fabricated using a computer-aided design/computer-aided manufacturing (CAD/CAM) system was better than a prefabricated one for the treatment of a severely damaged anterior tooth.

The load capability of endodontically treated teeth restored with posts is closely related to horizontal bone loss. Periodontitis not only causes bone loss, but also increases the failure rate of endodontic treatments [12]. A linear relationship was discovered between the amount of horizontal bone loss and the magnitude of force encountered by restored teeth [13].

The purpose of the present study was to evaluate the stress distribution of a severely damaged maxillary anterior tooth with differing levels of alveolar bone loss that was restored with a CAD/CAM glass-fiber post system, using the finite element method (FEM).

2. Materials and methods

An extracted, sound maxillary canine without cracks, fractures, or caries, obtained from the Department of Anatomy of the Southern Medical University, was selected in compliance with the standard criterion of a Chinese human tooth. The sample was 29.8 mm long, with crown and root lengths of 11.5 mm and 18.3 mm, respectively. Four different thicknesses of cervical dentin (1, 1.5, 2, and 2.5 mm) were studied. Alveolar bone loss was evaluated at horizontal bone levels of 1/3, 1/2, 2/3, and no bone loss (Figures 1 and 2). Models were endodontically treated and restored with a CAD/CAM glass-fiber post and core as well as a complete lithia-disilicate-based glass ceramic crown. Adhesion at all interfaces was considered equal.

A two-dimensional FEM was constructed based on the labiolingual cross-sectional anatomical measurements of the sample. ABAQUS 6.6 software was used as a platform for the FEM. The model was meshed with 3 degrees of freedom per node, thus resulting in a model with 6296 elements and 3267 nodes. The mechanical properties of the materials used in this study are listed in Table 1. A load

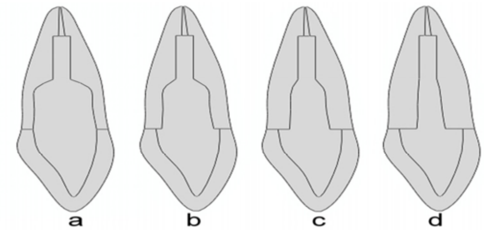

Fig. 1. Models with differing dentin wall thicknesses and boundary conditions. a: 1 mm, b: 1.5 mm, c: 2 mm, d: 2.5 mm.

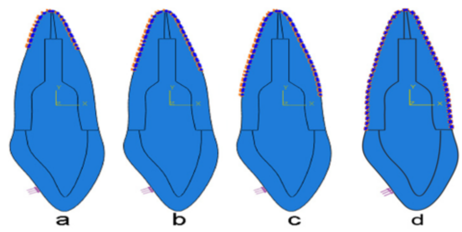

Fig. 2. Models with different boundary conditions simulating alveolar bone loss: a. 1/3 bone level, b. 1/2 bone level, c. 2/3 bone level, d. no bone loss.

of 100 N was applied to the crown at 45 degrees, 3 mm below the incisal edge of the lingual surface [14]. The maximal von Mises stresses in different regions and under different conditions were calculated. The relative ratio (RR) values of each group were calculated as follows:

$$\mathrm{RR} = p_{gi}/p_{max} \times 100\%$$

where p_{gi} (g = group number, i = 1, 2, 3…) represents the maximum von Mises stress (MM) of each condition in each group, and p_{max} represents the maximum MM in the group. An RR < 80% was considered to indicate a significant difference.

3. Results

The maximum von Mises stress was higher in the dentin than in the post and crown (Table 2 and Figures 3-5). With a reduction in dentin thickness, the maximum von Mises stress increased slightly and reached a peak at a thickness of 1.5 mm, followed by a slight decrease at a thickness of 1.0 mm (Table 3). However, all of the RR values of each bone level were higher than 80% and did not show large differences. Therefore, stress was not affected by dentin thickness.
The level of von Mises stress in the dentin was significantly affected by bone level (Table 4 and Figure 4). The RR values of each dentin wall thickness were all lower than 80% and showed significant differences, indicating that stress was significantly influenced by bone level.

4. Discussion

This study investigated stress distribution with diverse alveolar bone levels and cervical dentin wall

Table 2

Maximum von Mises stress values in different regions with various dentin wall thicknesses and bone levels (MPa)

Thickness of dentin wall	Lower 1/3			Middle 1/2			Upper 1/3			No bone loss		
	Dentin	Post	Crown	Dentin	Post	Crown	Dentin	Post	Crown	Dentin	Post	Crown
1.0 mm	486.2	121.6	81.03	293.4	48.91	73.36	173.8	43.46	86.92	142.6	39.2	85.8
1.5 mm	518.2	86.37	86.37	313.4	52.24	78.36	201.0	33.5	83.75	168.4	31.8	84.7
2.0 mm	470.8	117.7	78.47	262.9	43.81	87.62	171.5	42.88	85.75	139.7	38.4	84.9
2.5 mm	454.7	113.7	75.78	262.3	43.72	87.45	169.3	28.22	84.67	137.9	26.7	85.2

Table 3

Dentin relative ratio (RR) values of different bone levels

	Lower 1/3	RR	Middle 1/2	RR	Upper 1/3	RR	No bone loss	RR
1.0 mm	486.2	94%	293.4	94%	173.8	86%	142.6	86%
1.5 mm	518.2	100%	313.4	100%	201.0	100%	168.4	100%
2.0 mm	470.8	91%	262.9	84%	171.5	85%	139.7	83%
2.5 mm	454.7	88%	262.3	84%	169.3	84%	137.9	82%

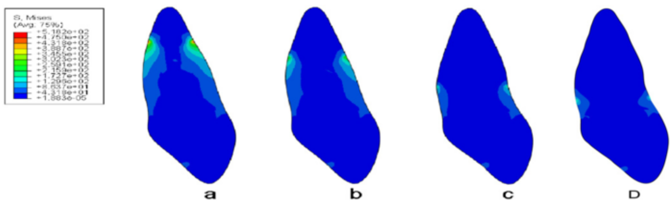

Fig. 3. Stress distribution in teeth with differing levels of bone loss and under 1.5 mm of dentin thickness. a: Bone level of lower 1/3, b: Bone level of 1/2, c: Bone level of upper 1/3, d: No bone loss.

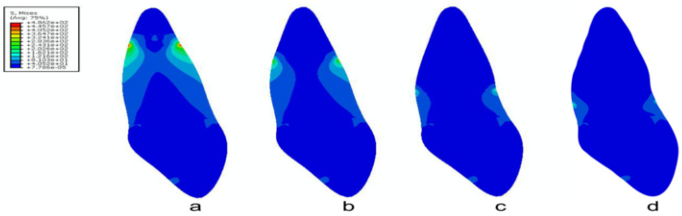

Fig. 4. Stress distribution in teeth with differing levels of bone loss and under 2.0 mm of dentin thickness. a: Bone level of lower 1/3, b: Bone level of 1/2, c: Bone level of upper 1/3, d: No bone loss.

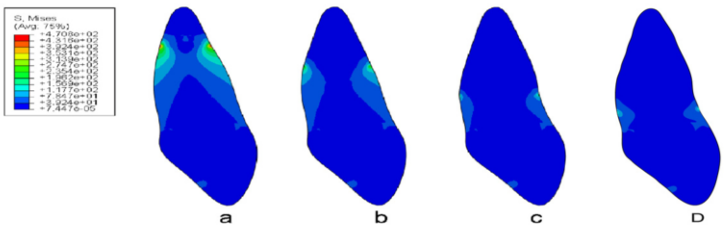

Fig. 5. Stress distribution in teeth with differing levels of bone loss and under 2.5 mm of dentin thickness. a: Bone level of lower 1/3, b: Bone level of 1/2, c: Bone level of upper 1/3, d: No bone loss.

thicknesses. The maximum von Mises stress was significantly reduced in the dentin when alveolar bone level increased, but was only slightly reduced when dentin wall thickness increased.

4.1. Alveolar bone level

Our results demonstrated a reduction in von Mises stress in a severely damaged tooth when alveolar bone level increased. There was no obvious stress concentration in the dentin except in the load

Table 4

Dentin RR values of different dentin wall thicknesses

	Lower 1/3	Middle 1/2	Upper 1/3	No bone loss
1.0 mm	486.2	293.4	173.8	142.6
RR	100%	60%	36%	29%
1.5 mm	518.2	313.4	201.0	168.4
RR	100%	60%	39%	32%
2.0 mm	470.8	262.9	171.5	139.7
RR	100%	56%	36%	30%
2.5 mm	454.7	262.3	169.3	137.9
RR	100%	58%	37%	30%

application and boundary restraint regions. At a bone level of 1/3 with a dentin wall thickness of 2.5 mm, the maximum von Mises stress was 454.7 MPa in the dentin; all stress values were higher than the dentin stress limit, which may increase the chance of root fracture [15]. In periodontitis patients, endodontic treatment of teeth induces more alveolar bone loss than that present in untreated teeth [16].

The results of the current study were similar to those of an in vitro study by Naumann, et al. [17], who found that the load capability reduced significantly with the loss of alveolar bone. In addition, Roscoe, et al. [12] discovered that stress concentration significantly increased when bone loss reached 5 mm. The effect of different bone levels on the maximum von Mises stress in the dentin is shown in Figure 4. The difference between the three bone levels tested was significant. An in vitro study [18] assessing the effects of the loss of alveolar bone from the area of the periodontal ligament found a decrease in the area of the periodontal ligament and a diminution of the fracture resistance of the root and post-core system. In addition, the force magnitude was probably reduced by the loss of horizontal bone, and the function of the tooth was damaged. Moreover, a long-term follow up found that maxillary fixed retainers might lead to accumulation of plaque, but had no significant influence on periodontal health [19].

4.2. Dentin wall thickness

In the current study, the differences in stress values between the four different dentin thicknesses tested were minor. The reason for this may be that changes in the dentin wall thickness take place only in the top area of the tooth and not in the lower area. With similar levels of alveolar bone loss, the maximum and minimum levels of stress were observed at thicknesses of 1.5 mm and 2.5 mm, respectively (Figure 6). Compared with a thickness of 1.5 mm, stress at a thickness of 2.5 mm was slightly increased in the post, but slightly decreased in the dentin (Figures 3 and 5). In general, stresses in the dentin were much larger than those in the post and crown (Table 2), so the fracture risk in the dentin was relatively higher. An in vitro study investigated the fracture resistance of different dentin thicknesses, and indicated that a thinner dentin layer significantly decreased the fracture resistance of severely damaged teeth restored with glass-fiber posts [20]. Moreover, an in vitro study [3] focusing on different degrees of substance loss pointed out that glass-fiber posts placed in endodontically treated premolars could only be preserved when fewer than 2 cavity walls were present. In the current

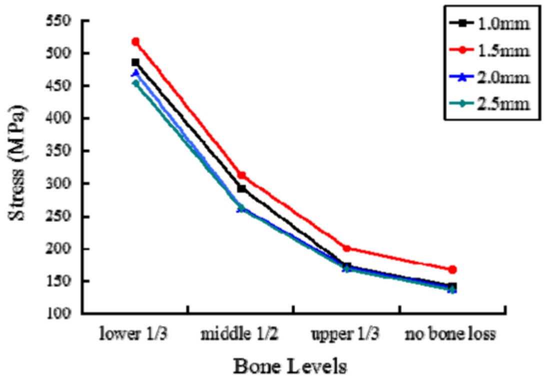

Fig. 6. Maximum von Mises stress in the dentin at different bone levels and dentin thicknesses.

study, the elastic modulus of the glass-fiber (20 GPa) was very similar to that of the dentin. The results of this study correlated with those of an in vitro study demonstrating that glass-fiber posts with a wider coronal diameter could be preserved well [21]. Therefore, in the case of a certain amount of retained tooth structure, a severely damaged canine restored with a CAD/CAM glass-fiber post system performed like a sound tooth when receiving an intraoral load [22].

When using the FEM, numerical results can be obtained easily in a shorter time via two-dimensional modeling. The FEM is known to be an initial step that can provide guidance for further laboratory tests and clinical research. Therefore, further clinical studies in this area are needed.

5. Conclusion

When using a CAD/CAM glass-fiber post system, the maximal von Mises stress was significantly affected by bone level, rather than by dentin thickness. Moreover, a CAD/CAM glass-fiber post system may be applied for the treatment of a severely damaged anterior tooth with a bone level of only 2/3.

Acknowledgments

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