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The three-dimension finite element analysis of stress in posterior tooth residual root restored with postcore crown

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Abstract – *Objective*: Teeth that have been endodontically treated and restored with postcore crown may experience fracture sometimes. Some researchers have analyzed the stress of the anterior teeth after postcore crown restoration, but the stress of the posterior teeth after such restoration has not been reported. We used three-dimension finite element methods to analyze the stress magnitude and distribution of remaining dentin in posterior tooth residual root restored with postcore crown. The binding material, loading direction, number, length and material of posts were studied. *Methods*: The models of residual root of maxillary first molar restored with postcore crown were created by CT scanning, MIMICS software and ABAQUS software. Different number, length and material of posts were used in the modeling. The posts were cemented with zinc-phosphate cement or composited resin. A load of 240 N was applied to the occlusal surface in four directions and tensile, shear, and von Mises stresses were calculated. *Result*: (i) The maximum stress on remaining dentin changed irregularly as the number and length of posts changed. (ii) The maximum stress on remaining dentin decreased slightly as elastic modulus of the material of posts increased. (iii) The maximum stress on bonding layer and remaining dentin was lower when bonded with resin luting agent than with zinc-phosphate cement. (iv) The maximum stress on remaining dentin increased markedly as loading angle increased. *Conclusion*: The number, length, material of posts, bonding material and loading angle all have influence on the magnitude and distribution of stress. The influence of loading angle is most apparent.

With the development of root canal therapy, residual roots of teeth have been widely preserved and restored with postcore crown. The teeth that have been endodontically treated and restored with postcore crown may experience fracture in some patients. The magnitude and distribution of stress in these tooth-restoration complexes are key points from the perspective of resistance to tooth fracture. Some researchers have analyzed the stress of the anterior teeth after postcore crown restoration (1–5). The shape, length, material of posts and luting agent all influence magnitude and distribution of stress in anterior tooth (6, 7). However, compared with the abundant research in anterior tooth, little is known about the posterior tooth restored with postcore crown. What is the relationship between post design and magnitude and distribution of stress in residual root of posterior teeth? How could we avoid fracture of posterior teeth more effectively by improving the design of prosthesis? Based on these questions, we performed this study to analyze the stress of remaining dentin in residual root of maxillary first molar restored with postcore crown by three-dimension finite element methods. The variables studied were bonding material, loading direction, number, length and material of posts. We speculated that each of the variables would more or less influence the stress in the tooth-restoration complex.

Materials and methods

The finite element method (FEM) was selected to analyze the stress of the teeth. This method is particularly suitable for biological structure analysis as it allows great flexibility in dealing with geometric complex domains composed by multiple materials. In this study, we applied dot-line-surface-body down to up modeling method. ABAQUS software was used as calculating platform. For simplification purpose, all materials were considered homogeneous, isotropic and linearly elastic. Boundary restrain was cortical bone fixed boundary. Furthermore, interface was assumed perfectly bound. All material parameters were shown in Table 1.

In the experiment, faultage pictures of maxillary first molar were acquired by CT scanning. Scanning condition is 120 Kv, 100 Ma. Scanning layer distance is

Table 1. Material and elastic modulus parameter

Material	Modulus (Gpa)	Poisson's ratio
Dentin (8)	18.6	0.31
Ligament (8)	0.0689	0.45
Cortical bone (8)	13.7	0.30
Trabecular bone (8)	1.37	0.30
Titanium (9)	112	0.33
Zirconia (10)	200	0.33
Gold (11)	93	0.33
Zinc phosphate cement (8)	22.4	0.25
Resin luting agent	8.0 (12)	0.30 (13)
Ceramic (14)	69.0	0.28

0.5 mm. Then, the faultage pictures were disposed with MIMICS software and accurate solid geometry model of maxillary first molar was built. The data of the solid geometry model were transited into ABAQUS software and afterwards the three-dimensional model of maxillary first molar was finished using CAD of ABAQUS software.

This FE model was divided into different geometric structures including the dentin, cortical bone, sponge bone, periodontal membrane, binding agent, porcelain crown, post and core. The shoulder around neck of teeth was 90°. In order to make calculation convenient, we ignored the influence of remaining canal filling material and replaced it with dentin. The three-dimensional model of maxillary first molar was meshed through Auto-Mesh-tool, and eight volumes, 20 512 elements and 80 015 nodes were generated at last.

In the first serial of the FE analysis, the number and length of posts were changed, as shown in Table 2. The posts studied in this series include: (i) palatal post with length of 1/2 of palatal root and mesio-buccal post with length of 1/2 of mesio-buccal root (abbr. 1/2PR & 1/2MBR), (ii) palatal post with length of 1/2 of palatal root and disto-buccal post with length of 1/2 of disto-buccal root (abbr.1/2PR & 1/2DBR), (iii) palatal post with length of 1/2 of palatal root and mesio-buccal post with length of 1/2 of mesio-buccal root and disto-buccal post with length of 1/2 of disto-buccal root (abbr.1/2PR & 1/2MDBR), (iv) palatal post with length of 2/3 of palatal root (abbr.2/3PR), (v) palatal post with length of 2/3 of palatal root and mesio-buccal post with length of 1/2 of mesio-buccal root (abbr.2/3PR & 1/2MBR), (vi) palatal post with length of 2/3 of palatal root and disto-buccal post with length of 1/2 of disto-buccal root (abbr.2/3PR & 1/2DBR) and (vii) palatal post with length of 2/3 of palatal root and mesio-buccal post with length of 1/2 of mesio-buccal root and disto-buccal post with length of 1/2 of disto-buccal root (abbr.2/3PR & 1/2MDBR).

In the second serial, the materials of posts were showed in Table 3. Gold, titanium alloy and zirconium oxide were all studied. The elastic modulus of them increased one by one.

In the third serial, the zinc-phosphate cement and resin binding agent were studied as shown in Tables 4 and 5.

In the fourth serial, the loading angle between loading direction and longitudinal axis of teeth varied from 0° to 90° bucally inclining as shown in Table 6.

Three nodes on the occlusal surface of maxillary first molar were selected to apply 80N load on each of them (Fig. 1). Thus a sum load of 240 N was applied on the model. The loading direction paralleled with the longitudinal axis of teeth to simulate the centric occlusal contact with the opposite teeth except in the fourth serial of study, where the loading direction

Table 2. Effect of different lengths and numbers of post

Load situation	Shape	Material	Cement	Loading angle	Maximum dentin stress (Mp)		
					Vo von mises	most principal	Shear
1	1/2PR & 1/2MBR	Gold	Zinc phosphate cement	0°	15.76	7.129	2.444
2	1/2PR & 1/2DBR	Gold	Zinc phosphate cement	0°	10.28	3.695	1.593
3	1/2PR & 1/2MDBR	Gold	Zinc phosphate cement	0°	11.63	3.783	2.010
4	2/3PR	Gold	Zinc phosphate cement	0°	14.27	4.854	2.485
5	2/3PR & 1/2MBR	Gold	Zinc phosphate cement	0°	11.84	3.839	2.002
6	2/3PR & 1/2DBR	Gold	Zinc phosphate cement	0°	12.94	4.633	2.202
7	2/3PR & 1/2MDBR	Gold	Zinc phosphate cement	0°	17.74	5.888	2.393

PR, palatal root; MDBR, mesio-buccal root and disto-buccal.

Table 3. Effect of different materials of post

Load situation	Shape	Material	Cement	Loading angle	Maximum dentin stress (Mp)		
					Vo von mises	most principal	Shear
7	2/3PR & 1/2MDBR	Gold	Zinc phosphate cement	0°	17.74	5.888	2.393
8	2/3PR & 1/2MDBR	Titanium alloy	Zinc phosphate cement	0°	16.74	5.529	1.966
9	2/3PR & 1/2MDBR	Zirconium oxide	Zinc phosphate cement	0°	16.17	5.409	1.896

PR, palatal root; MDBR, mesio-buccal root and disto-buccal.

Table 4. Effect of different bonding materials of post on bonding surface

Load situation	Shape	Material	Cement	Loading angle	Maximum Bonding layer stress (Mp) Von mises	most principal	Shear
7	2/3PR & 1/2MDBR	Gold	Zinc phosphate cement	0°	9.52	10.51	5.592
10	2/3PR & 1/2MDBR	Gold	Resin luting agent	0°	3.22	3.4960	0.7912

PR, palatal root; MDBR, mesio-buccal root and disto-buccal.

Table 5. Effect of different bonding materials of post on residual dentin

Load situation	Shape	Material	Cement	Loading angle	Maximum dentin stress (Mp) Von mises	most principal	Shear
7	2/3PR & 1/2MDBR	Gold	Zinc phosphate cement	0°	17.74	5.888	2.393
10	2/3PR & 1/2MDBR	Gold	Resin luting agent	0°	15.94	4.675	1.887

PR, palatal root; MDBR, mesio-buccal root and disto-buccal.

Table 6. Effect of varing loading angle

Load situation	Shape	Material	Cement	Loading angle	Maximum dentin stress (Mp) Von mises	most principal	Shear
7	2/3PR & 1/2MDBR	Gold	Zinc phosphate cement	0°	17.74	5.888	2.393
11	2/3PR & 1/2MDBR	Gold	Zinc phosphate cement	45°	27.14	9.962	3.120
12	2/3PR & 1/2MDBR	Gold	Zinc phosphate cement	60°	33.09	18.66	2.955
13	2/3PR & 1/2MDBR	Gold	Zinc phosphate cement	90°	33.60	35.28	4.16

PR, palatal root; MDBR, mesio-buccal root and disto-buccal.

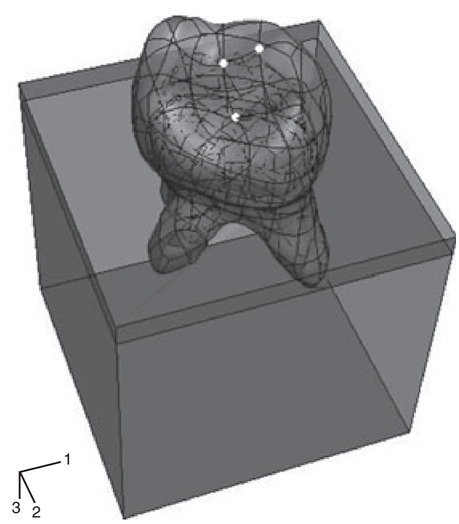

Fig. 1. The three-dimensional models of maxillary first molar. Three nodes on the occlusal surface of maxillary first molar were selected to apply 80 N load on each of them.

varied from 0° to 90° to the teeth longitudinal axis to simulate the laterotrusive occlusal contact with the opposite teeth.

Results

A convenient way of reporting the stress is in the form of color representation of the stress distributions, and a few examples are shown in Figs 2–5. However, this is so space consuming that it is impossible to show all figures in this article. Instead, the results are presented as the maximum stresses in tables. Stresses are existent, of course, in all the structures, but only dentin stresses or bonding layer stresses are reported here as shown in Tables 2–6.

Table 2 shows that the maximum stress on remaining dentin changed irregularly as the number and length of posts changed. Table 3 shows that the maximum stress on remaining dentin decreased slightly as elastic modulus of the material of posts increased. Table 4 shows that the maximum stress on bonding layer was lower when bonded with resin luting agent than with zinc-phosphate cement. Table 5 shows that the maximum stress on remaining dentin was lower when bonded with resin luting agent than with zinc-phosphate cement. Table 6 shows that the maximum stress on remaining dentin increased significantly as loading angle increased. The maximum tensile, shear and von Mises stress was greatest when the loading angle was 90° in all the situations.

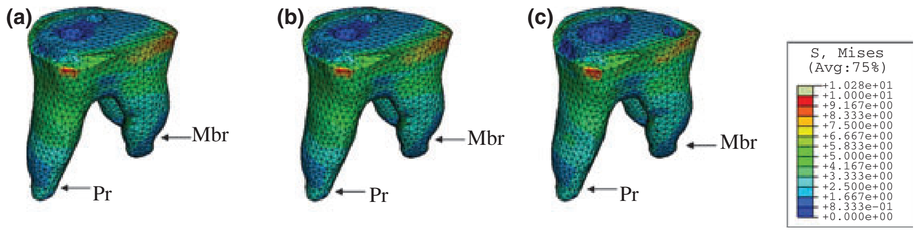

Fig. 2. Distribution of Von mises stress on dentin on condition of different number and length of post. (a) 1/2PR & 1/2MBR; (b) 2/3PR; (c) 2/3PR & 1/2MDBR. Areas with same color were subjected to same range of stress, as shown by numbers on right of colored rectangles. Distribution of stress of each group is much similar. Shoulder is high stress area. The maximum stress lies on shoulder of palatal root and mesiobuccal root. However, stress of other area is well-distributed and low. PR, palatal root; MBR, mesio-buccal root.

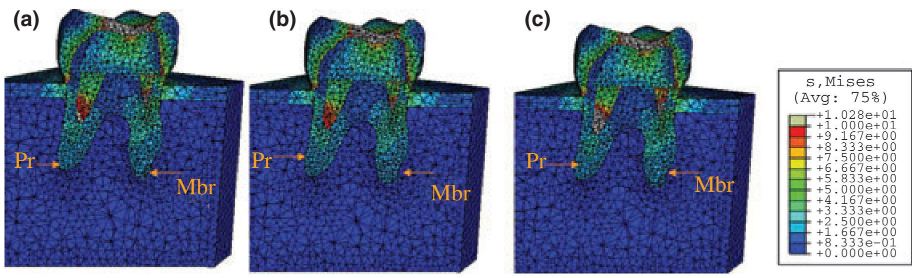

Fig. 3. Distribution of Von mises stress in buccal-palatal plane of teeth restored with postcore crown on dentin on condition of different post material. (a) Gold; (b) Titanium alloy; (c) Zirconium oxide. Areas with same color were subjected to same range of stress, as shown by numbers on right of colored rectangles. Distribution of stress of three groups was much similar, except in the point of palatal post. As elastic modulus of the material increased, high stress area decreased evidently. PR, palatal root; MBR, mesio-buccal root.

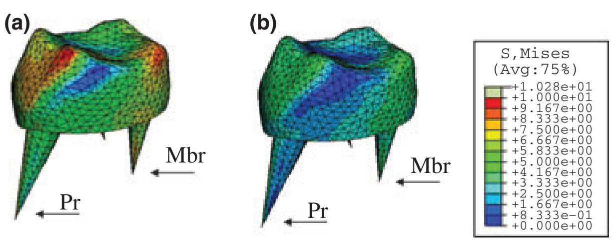

Fig. 4. Distribution of Von mises stress on bonding layer on condition of different bonding material. (a) Zinc phosphate; (b) Resin luting agent. Areas with same color were subjected to same range of stress, as shown by numbers on right of colored rectangles. Magnitude of Von mises stress on bonding layer of resin luting agent is far lower than Zinc phosphate. PR, palatal root; MBR, mesio-buccal root.

Discussion

In this study, maximum tensile, shear and von Mises stresses were investigated. Von mises stress is a comprehensive stress of each point in material and is a widely used indicator of the possibility of damage occurrence (11). Dentin is crisp and its compressive strength is five to six times higher than tensile strength. So we choose the von Mises stress and maximum tensile stress to assess the risk of tooth fracture after residual root is restored with postcore crown. If the tensile strength of dentin is assumed to the range of 50–100 MPa (15), the results reveal that maximum von Mises stress and maximum tensile stress on dentin in all studied situation are far lower than the tensile strength of dentin. Thereby, it is easy to draw the conclusion that residual root of posterior teeth will not fracture on condition of normal occlusal force after it is restored with postcore crown. Of course, practical occlusal force in clinic is sometimes larger than the normal occlusal force, and the biggest occlusal force of the maxillary first molar can achieve 480 N. When higher loads were applied, the corresponding calculated stresses would increase proportionally. If our result was used as the basic parameter, we can deduce that root fracture might occur when the angle between loading direction and tooth axis is more than 45° on condition of 480 N load.

Shear stress located at the interface between post and dentin and could damage the retention of the post. Calculated shear stress may be used to assess the risk of loss of retention of the post. Dentin bonding system provided bonding strength about 15–30 MPa (16), and zinc-phosphate cement would lose retention when shear stress reached 5–25 MPa (17, 18). As the same, if our result was used as the basic parameter, retention provided by zinc-phosphate cement would be damaged on condition of normal 240 N occlusal force, which would lead to loosing and falling of post at last. However, the resin luting agent could avoid the risk of losing retention.

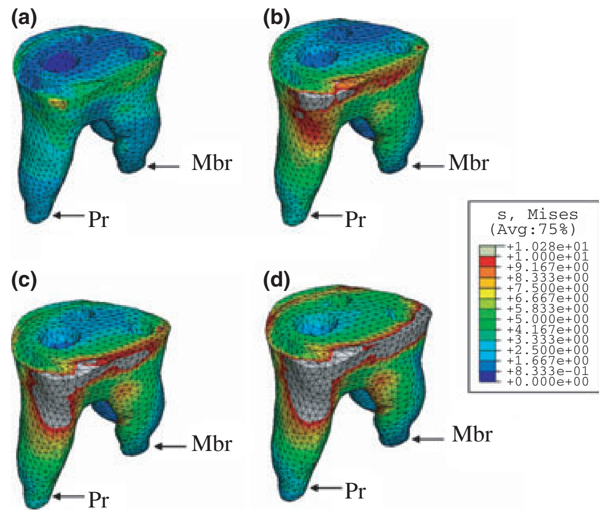

Fig. 5. Distribution of Von mises stress on dentin on condition of different loading direction. (a) 0°; (b) 45°; (c) 60°; (d) 90°. Areas with same color were subjected to same range of stress, as shown by numbers on right of colored rectangles. Magnitude of Von mises stress on dentin increases markedly in neck areas of palatal root as loading angle increases. PR, palatal root; MBR, mesio-buccal root.

When residual roots of posterior teeth were restored, different length and number of posts could be chosen. It is important to consider magnitude and distribution of the stress on the remaining dentin of different post design because the stress will directly influence resistance of root fracture. Table 2 shows that the maximum stresses on remaining dentin change irregularly as the number and length of posts change, but they are all far lower than the tensile strength of dentin. Distribution of stress of each group is much similar. Shoulder is high stress area. The maximum stress lies on shoulder of palatal root and mesiobuccal root. Otherwise, stress of other area is well-distributed and low. Stress on root canal wall is much lower. Holmes (8) concluded in a FE study on anterior teeth that peak dentinal tensile stresses occurred in the gingival third of the facial root surface and the distribution of tensile stress was not affected by variation in the dimensions of the posts. Toksavul (19) also found that the greatest stresses occurred in the coronal third of the roots on facial surfaces of anterior teeth. Nakamura (20) suggested that to reduce the stresses that cause root fracture, a long, thin fiber post should be used for the endodontically treated anterior teeth. Compared with anterior teeth, the magnitude and distribution of stress on posterior teeth residual roots restored with postcore crown was different. The difference may come from different loading direction on posterior teeth and anterior teeth. The loading direction is 45° oblique to the longitudinal axis in anterior teeth study while parallel to the longitudinal axis in posterior teeth study. In the latter, the bottom of pulp chamber and shoulder bore and dispersed the stress, which lowered the maximum stresses on remaining dentin. According to our result, we can conclude that there is little influence on stress of remaining dentin and root will not fracture when the number and length of posts vary. The result also indicates that in order to increase retention provided by post, we may add the number of posts and lengthen the length of posts as possible as we can in clinic practice.

The elastic modulus is an important parameter of postcore material. The increasing of the elastic modulus of the post was found to cause the slight decrease of the dentin stress in our study. It was reported that low elastic modulus post would transfer more stress to dentin and lower stress on itself, while high elastic modulus post would take on more stress on itself and transfer less stress to dentin. The former was advantageous to post, and the latter was favorable to dentin (6, 21, 22). Our result accords with them in the point that the maximum stress on remaining dentin decreased as elastic modulus of the post increased. However, the change of stress in this study is not as distinct as others. Genovese (23) also concluded in an FE study that maximum stress values in restored teeth are rather insensitive to post types and materials. Our result is consistent with Genovese. It is clear that different postcore material has little influence on the stress of the remaining dentin.

When bonding material of post is chosen, we should consider not only its retention force but also its resistance to damage under stress. Bonding material is the media which transmit and diffuse stress between post and dentin. The elastic modulus and mechanical character of it have important influence on stress transmitting and diffusing. Li (24) demonstrated that elastic modulus was indeed one of the important parameters to evaluate property of the cements. In his study, with the increasing of the elastic modulus of cements, the stress values in dentin decreased (respectively, for maximum principle stress values and Von Mises stress values). On the other hand, maximum principle stress value and Von Mises stress value in cement layer increased with the increasing of the elastic modulus of cements. The elastic modulus of zinc-phosphate cement was much bigger than the resin luting agent. In our study, the stress in bonding layer was also bigger when zinc-phosphate cement was used. However, the stress in dentin didn't change obviously when zinc-phosphate cement or resin luting agent was used. In our experiment, it was disadvantageous for zinc-phosphate cement which would lose retention when shear stress got to 5–25 Mpa, as stress value in cement layer increased with the increasing of the elastic modulus of cements. On the contrary, the low elastic modulus of resin luting agent showed good character in lowering stress on itself. Thus, resin luting agent may be a better choice for the restoration of residual roots in clinical practice.

In this study, the number, length, material of post, bonding material and loading angle all have influence on the magnitude and distribution of stress. However, the influence of loading angle is the most apparent. Yang (25) also pointed out the direction of the functional load had a greater effect than the dowel design on maximum stress and displacement. If our result was used as the basic parameter, we can deduce that the root will fracture when the angle between the loading direction and tooth axis is more than 45° on condition of the biggest occlusal force. The oblique loading force can not only increase the stress value on the remaining dentin, but also can enlarge the high stress area and make the surface of the gingival third of palatal root high stress area. This will increase the possibility of root fracture. Our results indicated that cusp inclining angle of crown should be reduced when posterior tooth residual root is restored with postcore crown, in order to lower magnitude and rationalize the distribution of stress on dentin, which will reduce the risk of root fracture and lengthen the longevity of prosthesis.

Conclusion

Within the limitation of the in vitro study, the following conclusions were drawn:

1 The number, length, material of post, bonding material and loading angle all have influence on the magnitude and distribution of stress in posterior tooth residual root restored with postcore crown.
2 Resin luting agent is a better choice for the bonding of post compared with zinc-phosphate cement in clinical practice.
3 When posterior tooth residual root is restored with postcore crown, we should reduce cusp inclining angle as possible as we can.

References

1. Reinhardt RA, Krejci RF, Pao YC, Stannard JG. Dentin stresses in postreconstructed teeth with diminishing bone support. J Dent Res 1983;62:1002–8.
2. Ko CC, Chu CS, Chung KH, Lee MC. Effects of posts on dentin stress distribution in pulpless teeth. J Prosthet Dent 1992;68:421–7.
3. Ukon S, Moroi H, Okimoto K, Fujita M, Ishikawa M, Terada Y et al. Influence of different elastic moduli of dowel and core on stress distribution in root. Dent Mater J 2000;19:50–64.
4. Yang HS, Lang LA, Molina A, Felton DA. The effects of dowel design and load direction on dowel-and-core restorations. J Prosthet Dent 2001;85:558–67.
5. Albuquerque Rde C, Polleto LT, Fontana RH, Cimini CA. Stress analysis of an upper central incisor restored with different posts. J Oral Rehabil 2003;30:936–43.
6. Asmussen E, Peutzfeldt A, Sahafi A. Finite element analysis of stresses in endodontically treated, dowel-restored teeth. J Prosthet Dent 2005;94:321–9.
7. Nakamura T, Ohyama T, Waki T, Kinuta S, Wakabayashi K, Mutobe Y et al. Stress analysis of endodontically treated anterior teeth restored with different types of post material. Dent Mater J 2006;25:145–50.
8. Holmes DC, Diaz-Arnold AM, Leary JM. Influence of post dimension on stress distribution in dentin. J Prosthet Dent 1996;75:140–7.
9. Toparli M. Stress analysis in a postrestored tooth utilizing the finite element method. J Oral Rehabil 2003;30:470–6.
10. Christel P, Meunier A, Heller M, Torre JP, Peille CN. Mechanical properties and short-term *in-vivo* evaluation of yttrium-oxide-partially-stabilized zirconia. J Biomed Mater Res 1989;23:45–61.
11. Pegoretti A, Fambri L, Zappini G, Bianchetti M. Finite element analysis of a glass fibre reinforced composite endodontic post. Biomaterials 2002;23:2667–82.
12. Attar N, Tam LE, McComb D. Mechanical and physical properties of contemporary dental luting agents. J Prosthet Dent 2003;89:127–34.
13. Ausiello P, Apicella A, Davidson CL. Effect of adhesive layer properties on stress distribution in composite restorations–a 3D finite element analysis. Dent Mater 2002;18:295–303.
14. Yaman SD, Alacam T, Yaman Y. Analysis of stress distribution in a maxillary central incisor subjected to various post and core applications. J Endod 1998;24:107–11.
15. Kinney JH, Marshall SJ, Marshall GW. The mechanical properties of human dentin: a critical review and re-evaluation of the dental literature. Crit Rev Oral Biol Med 2003;14:13–29.
16. Asmussen E, Peutzfeldt A. The influence of relative humidity on the effect of dentin bonding systems. J Adhes Dent 2001;3:123–7.
17. Johnson JK, Sakumura JS. Dowel form and tensile force. J Prosthet Dent 1978;40:645–9.
18. Drummond JL, Toepke TR, King TJ. Thermal and cyclic loading of endodontic posts. Eur J Oral Sci 1999;107:220–4.
19. Toksavul S, Zor M, Toman M, Gungor MA, Nergiz I, Artunc C. Analysis of dentinal stress distribution of maxillary central incisors subjected to various post-and-core applications. Oper Dent 2006;31:89–96.
20. Nakamura T, Ohyama T, Waki T, Kinuta S, Wakabayashi K, Mutobe Y et al. Stress analysis of endodontically treated anterior teeth restored with different types of post material. Dent Mater J 2006;25:145–50.
21. Pierrisnard L, Bohin F, Renault P, Barquins M. Corono-radicular reconstruction of pulpless teeth: a mechanical study using finite element analysis. J Prosthet Dent 2002;88:442–8.
22. Eskitascioglu G, Belli S, Kalkan M. Evaluation of two post core systems using two different methods (fracture strength test and a finite elemental stress analysis). J Endod 2002;28:629–33.
23. Genovese K, Lamberti L, Pappalettere C. Finite element analysis of a new customized composite post system for endodontically treated teeth. J Biomech 2005;38:2375–89.
24. Li LL, Wang ZY, Bai ZC, Mao Y, Gao B, Xin HT et al. Three-dimensional finite element analysis of weakened roots restored with different cements in combination with titanium alloy posts. Chin Med J (Engl) 2006;119:305–11.
25. Yang HS, Lang LA, Molina A, Felton DA. The effects of dowel design and load direction on dowel-and-core restorations. J Prosthet Dent 2001;85:558–67.