Three-dimensional finite element analysis (3D-FEA) of stress distribution on all-ceramic crown and residual dentin with different types of post material

Li Bing, Xiuping Wu *, Liu Fei , Jingjing Deng , Bingsheng Zhang

Stomatology Hospital, Shanxi Medical University, 63 Xinjian South Road, Taiyuan, Shanxi 030001, China.
Tel: 13934232658; E-mail: 77wxp@163.com

Abstract: Objective: To investigate the relationship between the different teeth post and core materials and stress distribution of all-ceramic crown and residual dentin and provide the basis for the design of clinical repair. Methods: The fault images of spiral CT were used to construct the finite element analysis model of 1/2 defect in lingual side of maxillary first molar and all-ceramic crown, and load way was designed: 600N load was vertically concentrated, and ANSYS software was used to analyze the stress values of all-ceramic crown and dentin. Results: The von mises stress of all-ceramic crown and maximum tensile stress loads are concentrated on the loading area and was decreased progressively and radially towards surrounding. The concentration region of von mises stress was extended towards buccal side; The von mises stress of dentin was concentrated on the contact part of the gnathic side of prepared body of abutment in buccal side and all-ceramic crowns, the maximum tensile stress was concentrated on tooth neck in buccal side of the prepared body of abutment in buccal side. Conclusions: Because different teeth post and core materials can affect the stress distribution of all-ceramic crown and residual dentin significantly. In clinic, the suitable teeth post and nuclear materials were chosen according to dental defect of patients.

[Li Bing, Xiuping Wu, Liu Fei, Jingjing Deng, Bingsheng Zhang. **Three-dimensional finite element analysis (3D-FEA) of stress distribution on all-ceramic crown and residual dentin with different types of post material.** *Life Sci J* 2013;10(4):1302-1308]. (ISSN:1097-8135). http://www.lifesciencesite.com. 172

Keywords: the maxillary first molar；all-ceramic crown；finite element analysis; stress; dentin

1. Introduction

In the management of endodontically treated teeth abutment construction is performed followed by prosthetic crown restoration. However, root fractures are occasionally observed in endodontically treated teeth. It has been reported that preserving the coronal tooth structure is effective and essential for preventing such fractures（Yaman S-D et al，1998）. The use of a post is indispensable for the retention of the core. It has been advocated that the use post and core is effective in retaining an artificial crown for teeth with a larget coronal defect.

With the development of medical technology and the continuous improvement of people's aesthetic requirements, all-ceramic restoration techniques for its unique esthetical properties and biocompatibility have been widely used in clinic. After the all-ceramic restoration technology has been developed for many years, the scope of the anterior teeth restoration extended to the posterior teeth, from a single crown to a fixed bridge. These are related to the inventions of a variety of high-strength all-ceramic materials（A. Imanishi et al，2003；N. Hochman and M. Zalkind, 1999）. The object of inceram-Z all-ceramic materials studied in this experiment which is developed by Vita company are used as all-ceramic crowns on posterior teeth and all-ceramic fixed bridge restoration. They are high-strength all-ceramic materials which are made by using glass infiltrates alumina. The technology effectively improves the strength of the materials.

Many factors can affect the strength of all-ceramic crowns. Different material of post-core must affect the stress results of all-ceramic crowns (Lü Xiao-chun, and Cheng Xiang-rong, 2008), while changes in the distribution of stress can also affect the life of all-ceramic restorations. Inceram-Z all-ceramic crown is our research object in this experiment. Finite element analysis (FEA) is a popular numerical method in stress analysis (P.H. Dehoff and K.J. Anusavice, 1989; E. Dianne Rekowa et al, 2006). FEA shows the internal stresses and, on that basis, predictions about failure can be made. The effect of post design, post material and core material is very important on dentinal and All-ceramic crown stress distribution (Natalie Reznikov et al, 2010; Lu Cheng-lin, Wu Yan-ling et al, 2009; Gürcan Eskitascioglu et al, 2002).

We used three-dimensional finite element method to build the all-ceramic crown of the maxillary first molar in order to observe the effects in all-ceramic crown and dentin. The effects are made by different material of post-core(Takashi Nakamura et al,2006; Kazuhiko Okamoto et al,2008; Fu Gang et al,2009). In a word, this study can provide a theoretical basis for optimization design of all-ceramic crown.

In this experiment, we used three-dimensional finite element as research method. First, an intact maxillary first molar in vitro was selected. Second, it was scanning by the Computed Tomographic (CT) after embedding it and the pictures are saved as DICOM form. Third, MIMICS and ANSYS software were used to set up all-ceramic crown of the maxillary first molar, half of which is lost in lingual side of the maxillary first molar, with restoration of different post-core and all-ceramic crown(Fu Gang et al,2006; L in Chuan et al, 2008; Li Jian et al,2007). Then a 600N force is applied vertically downward. Finally, the parameters of material properties and boundary conditions in biomechanical analysis were used to analyze in order to study the stress distribution of all-ceramic crown and dentin (Jia Jun et al,2006).

2. Materials and methods

2.1. The construction of three-dimensional finite element model

An integrity maxillary first molar in vitro was chosen, it had no wear, no caries, no root absorption. Its full length was 19.7mm, crown length 7.3mm and root length 12.4mm. Its crown width was 10.1mm and neck width 7.6mm. Its crown thickness was 11.3mm and neck thickness 10.5 mm. Epoxy resin was embedded in to 4cm × 4cm rectangular metal body, and made the long axis of tooth perpendicular to the bottom of embedding material. 64-slice spiral CT was used to tomoscan for this embedding model, and the slice thickness was 0.6mm, slice spinula was 0.1mm, 212 images obtained from maxillary first molar were saved as DICOM format. Then the digital images in DICOM format were imported into MIMICS software. ANSYS modeling software with pre-treatment was used and the preparation body of abutment tooth model in buccolingual direction were divided equally. And the 1/2 of model was removed in lingual direction. Then, the finite element model of 1/2 defect of upper first molar in lingual side was established. A taper post was established by utilizing the function of generating unit body directly in ANSYS software. The shape of this post was similar as the lingula root of maxillary first molar model. Its diameter was about 1/3 of lingula root, and its length was about 2/3 of lingula root. The entity of post was inserted at 4mm away from the root tip of lingula root. 4mm gutta percha point was kept in root tip. Then this post and 1/2 defect of upper first molar preparation body in lingual side were bond by using ANSYS software, thus a finite element model 1/2 defects of maxillary first molar lingual after repair of post-core crown was established (Wu Yan-ling et al,2009).

The model was divided by network automatical division tool of ANSYS software. The isoparametric tetrahedral finite element analysis of three-dimensional models with 20 nodes of topology form of were generated, and 31,244 units and 48,420 nodes including all-ceramic crowns, dental prosthetic restoration of post and core, residual dental, gutta percha point, periodontal ligament, alveolar bone. Five posts and nuclear material were designed in this experiment as follows: ① ordinary composite resin; ② quartz fiber post; ③casting porcelain post and core; ④alloy gold post and core⑤ Ni-Cr alloy post and core coated with 0.5mm masking porcelain.

2.2 Loading style

The location of loading was in the central region of the gnathal surface of maxillary first molar. The loading style was static loading. The size of force was 600N, and the direction of was force parallel to the long axis of tooth.

2.3 Mechanical parameters of materials

Mechanical parameters of materials were shown in Table 1

2.4 The assume of experimental conditions

The materials and tissues in this assuming experimental model were continuous, homogeneous and isotropic linear elastomeric materials, relative sliding was not produced between the interfaces of various components when the model was forced, The kind of deformation is small deformation. The constrained condition of boundary was fixed and constrained for the bottom of alveolar bone.

2.5 The observation indexes

Because all-ceramic crowns and tooth tissue were brittle materials, which were resistant to pressure and not to tension, so in this experiment the first principal stress (S1), which can reflect maximum tensile stress of some point of material, was used as observation index, while the von mises stress can reflect the combined stresses of some point in material and it can reflect the state of stress in the material. So in this experiment von mises stress was considered as an observation index of all-ceramic crowns and dentin.

3. Results

3.1 The stress distribution of all ceramic crown of 1/2 defects in lingual side of maxillary first molar after the repair of different post and core materials

Von mises stress and maximum tensile stress loads were concentrated on the loading area and was decreased progressively and radially towards surrounding. The concentration region of von mises stress was extended towards buccal side. Stress distribution of all ceramic crown of 1/2 defects in lingual side of maxillary first molar after the repair of different post and core materials were shown in Figure 1 to Figure 4. The stress peaks of the all ceramic crown after the repair of different post and core materials was shown in Table 2.

3.2 The stress distribution of dentin of 1/2 defects in lingual side of maxillary first molar after the repair of different post and core materials

The von mises stress of dentin was concentrated on the contact part of the gnathic side of prepared body of abutment in buccal side and all-ceramic crowns, the maximum tensile stress was concentrated on tooth neck in buccal side of the prepared body of abutment in buccal side. Stress distribution of dentin of 1/2 defects in lingual side of maxillary first molar after the repair of different post and core materials were shown in Figure 1 to Figure 4. The stress peaks of the dentin after the repair of different post and core materials was shown in Table 2.

4. Discussions

After the repair of different post and core materials, the stress analysis results of all-ceramic crowns suggested that the von mises stress of all-ceramic crown and maximum tensile stress loads are concentrated on the loading area and was decreased progressively and radially towards surrounding. The concentration region of von mises stress was extended towards buccal side.

The peak values of von mises stress and the maximum tensile stress values of the post-core materials were increased with the decrease of elastic modulus of the five post-core materials, the magnitude of elastic modulus of five post and core materials was: Ni-Cr alloy post-core> gold alloy post core > casting porcelain post and core> quartz fiber posts> ordinary composite resin, which was contrary to the order of the stress values of all-ceramic crowns materials. As shown in Table 2, the peak values of all-ceramic crowns von mises stress were from 82.3 to 188 MPa, and the maximum principal stress values were from 47.1-113 MPa, while the bending strength of all-ceramic crown is much higher than the maximum values, which indicated that the selected five post and core materials in this experiment can be applied to all-ceramic restoration in theory.

As shown the stress contribution figure of all-ceramic crown, the range of its high-stress distribution of gnathal side all-ceramic crowns treated with Ni-Cr alloy post core with high elastic modulus was smaller, while the range of its high-stress distribution of gnathal side all-ceramic crowns treated with post core materials with lower elastic modulus was larger. The range of its high-stress distribution of gnathal side all-ceramic crowns treated with general composite resin was the largest among them, so the possibility of its fracture was also greater.

After the repair of post and core materials in this experiment, stress analysis results of residual dentin in different post and core materials suggested that The von mises stress of dentin was concentrated on the contact part of the gnathic side of prepared body of abutment in buccal side and all-ceramic crowns, the maximum tensile stress was concentrated on tooth neck in buccal side of the prepared body of abutment in buccal side.

The experimental results showed that after the restoration of the five kinds of post-core materials, the von mises stress and maximum tensile stress values of lingual 1/2 defect of maxillary first molar remaining tooth tissue were compared. Ordinary composite resin post > quartz fiber posts > casting porcelain post > gold alloy post > Ni-Cr alloy post, the stress values of the five post and core materials have inverse proportion to elastic modulus of post and core materials. The greater the elastic modulus of the post and core material, the smaller the stress of residual dentin. In this study, the stress peak value of residual dentin of nickel-chromium alloy post core with a high elastic modulus was minimal, its von mises stress peak value of remnant dentin was decreased by 56.1% and its the maximum tensile stress value was decreased by 41.4% compared to that of composite resin post-core. There results were consistent with the study of foreign Yaman, etc (Kazuhiko Okamoto et al, 2008). It was found that the decrease of the maximum stress of dentin restored by post-core does not exceed 6.2% under chewing loads and traumatic loads, when it is assumed the elastic modulus of post material was three-fold of that of stainless steel, the maximum stress was reduced to 11% of that of dentin. Under vertical load, the maximum stress of gold alloy post and core dentine was reduced and reached to 20%, while the stress of ordinary steel post dentin was reduced to 35%. Ho adopted three-dimensional finite element to analyze stress conditions of central incisor on the collar after the restoration of the post-core materials found that under diagonal and horizontal loading(S Toksavul et al,2006), the stress peak value of teeth after restoration by stainless steel post can be reduced to 9.9-14.5%, while the the stress peak value of gold alloy post was reduced to 6.9- 9.6%, but did not change its stress distribution form. Because when the casting post and core materials with higher modulus of elasticity was used to restore, the tooth stress is mainly concentrated on casting post and core, less stress was transfered to the supporting tissues and teeth, which is favorable to teeth and supporting tissues, while composite resin post-core with lower modulus of elasticity was used to restore, less stress was concentrated on the post-core system, main stress was used for supporting tissues and tooth, which was favorable to repairing body but not conducive to supporting tissues (Zhang Yu-xing et al, 2006). Therefore, when post-core crown was restored for clinical residual crown and root, the post and core materials with a higher modulus of elasticity should be used, so it is favorable for protecting remnant tooth tissue.

In summary, in clinic, the elastic modulus is not the only reference criteria for the choice of post-core materials, in addition, the conditions of dental root, occlusal conditions, and the full ceramic materials were also considered.

Table 1. Mechanical parameters of materials

material	Young's modulus(MPa)	Poisson's ratio
dentin	1.86×10^4	0.31
pericementum	70.3	0.45
alveolar bone	1.37×10^4	0.30
gutta percha	68.9	0.45
Inceram-Z all-ceramic	2.05×10^5	0.31
ordinary composite resin	8.3×10^3	0.28
quartz fiber	1.5×10^4	0.30
casting porcelain	6.89×10^4	0.28
gold alloy	1.02×10^5	0.33
Ni-Cr alloy	2.1×10^5	0.33

Table 2. **The stress peaks of the all ceramic crown and dentin, as well as Von Mises**

material	The stress peaks			Von Mises stress	
	all ceramic crown	dentin		all ceramic crown	dentin
ordinary composite resin	113	8.01		188	35.3
quartz fiber	83.1	7.09		155	30.4
casting porcelain	79.8	6.85		123	25.3
gold alloy	51.2	6.79		108	21.9
Ni-Cr alloy	47.1	4.69		82.3	15.5

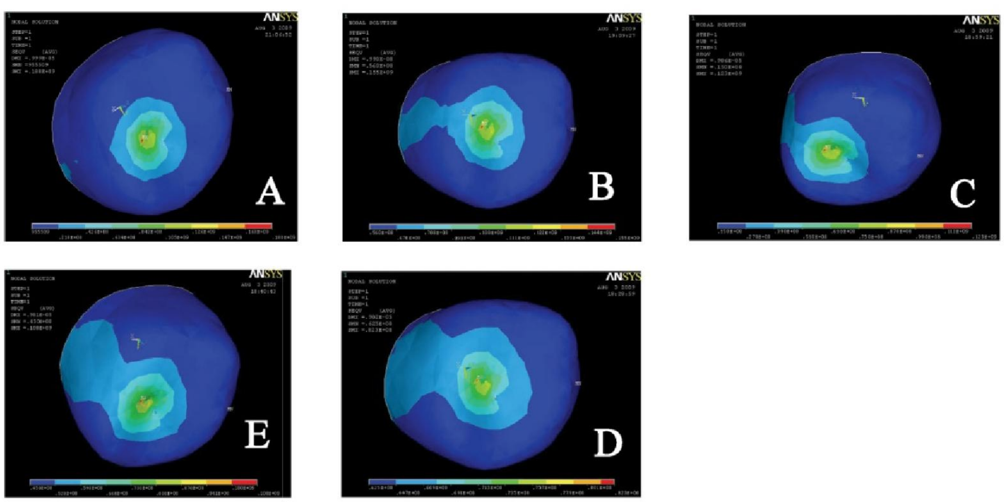

Figure 1. The von mises stress distribution figures of Inceram-Z all-ceramic crown of five post and core materials. A. ordinary composite resin; B. quartz fiber; C. casting porcelain post and core; D. gold alloy post and core; E. Ni-Cr alloy post and core.

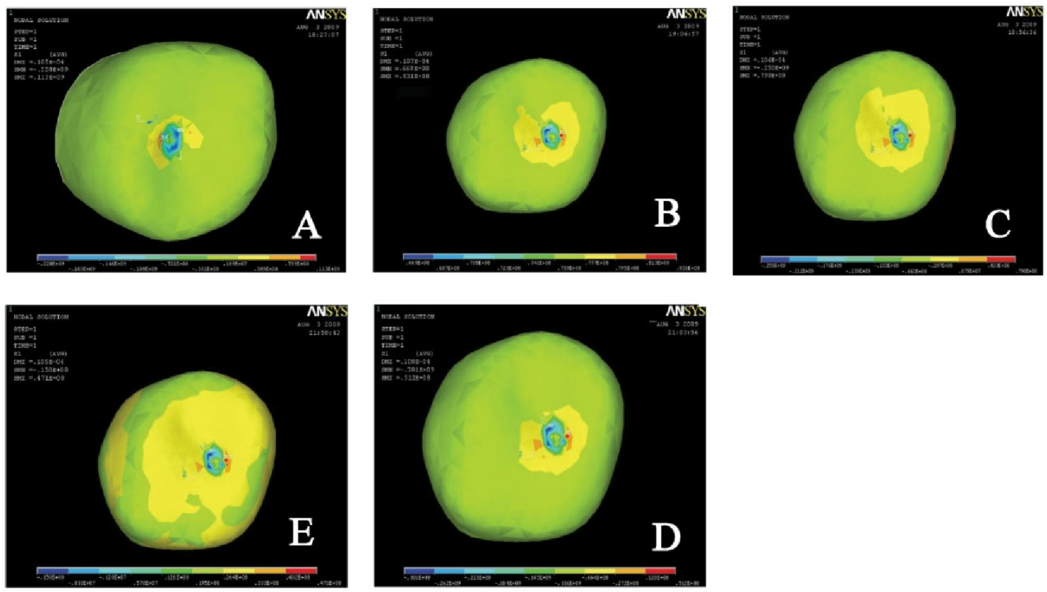

Figure 2. The S1 stress distribution figures of Inceram-Z all-ceramic crown of five post and core materials. A. ordinary composite resin; B. quartz fiber; C. casting porcelain post and core; D. gold alloy post and core; E. Ni-Cr alloy post and core.

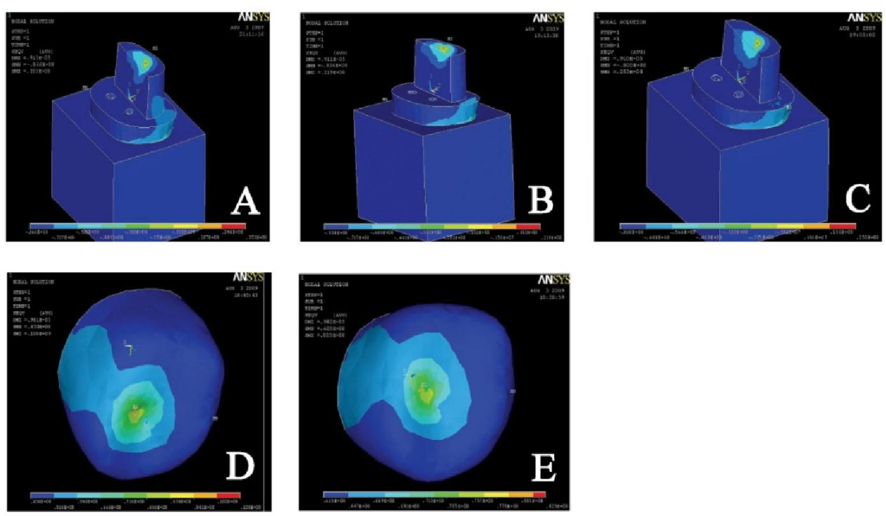

Figure 3. The von mises stress distribution figures of Inceram-Z dentin of five post and core materials. A. ordinary composite resin; B. quartz fiber; C. casting porcelain post and core; D. gold alloy post and core; E. Ni-Cr alloy post and core.

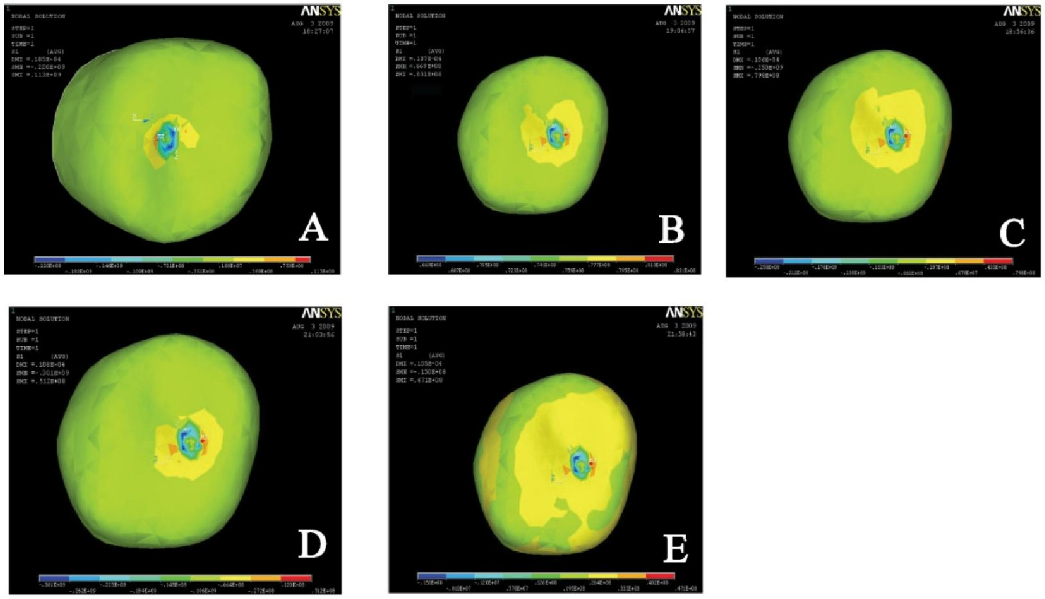

Figure 4. The S1 stress distribution figures of Inceram-Z dentin of five post and core materials. A. ordinary composite resin; B. quartz fiber; C. casting porcelain post and core; D. gold alloy post and core; E. Ni-Cr alloy post and core.

Acknowledgements:

This work was supported by Shanxi Medical University, China. (grant#: 02200721). Points of view in this document are those of the authors and do not necessarily represent the official position of Shanxi Medical University, China.

***Corresponding author:**
Xiuping Wu
Professor of Department of Stomatology
Shanxi Medical University
63 Xinjian South Road
Taiyuan 030001, China
Tel: 13934232658
E-mail: 77wxp@163.com

References

1. Yaman S-D, Alacam T, Yaman Y. Analysis of stress distribution in a maxillary central incisor subjected to various post and core applications. J-Endod 1998; 24(2): 107
2. A. Imanishi, T. Nakamura, T. Ohyama, et al. 3-D Finite element analysis of all-ceramic posterior crowns. Journal of Oral Rehabilitation 2003;30（4）:818-822
3. N. Hochman, M. Zalkind. New all-ceramic indirect post-and-core system. J Prosthet Dent 1999;81（6）:625-629
4. Lü Xiao-chun, Cheng Xiang-rong. Different kinds of post core materials effects on In-ceram full-porcelain crown stress of the first premolar using finite element analysis. J Zhongguo Zuzhi Gongcheng Yanjiu yu Linchuang Kangfu 2008;12 (19): 3667- 3670
5. P.H. Dehoff, K.J. Anusavice. Effect of Visco-elastic behavior on stress development in a Metal-Ceramic System. J Dent Res 1989; 68(8):1223-1230
6. E. Dianne Rekowa, Masly Harsonob, Mal Janal, et al. Factorial analysis of variables influencing stress in all-ceramic crowns. J Dental Materials 2006; 22（3）: 125-132.
7. Natalie Reznikov, Gilad Har-Zion, Idit Barkana, et al. Influence of friction resistance on expression of superelastic properties of Initial NiTiWires in “Reduced Friction” and conventional bracket systems. Journal of Dental Biomechanics 2010; 25 (7):11-17
8. Lu Cheng-lin, Wu Yan-ling, Zhang Xiu-yin, et al. Stress analysis of the all-ceramic crown witll a numerical approach. Chin J Stomatol 2009; 44(3):155-158
9. Gürcan Eskitascioglu, Sema Belli, Mustafa Kalkan. Evaluation of two post core systems using two different methods (fracture strength test and a finite elemental stress analysis). Journal of Endodontics 2002; 28(9):629-633
10. Takashi Nakamura, Tatsuo Ohyama, Tomonori

Waki, et al. Stress analysis of endodontically treated anterior teeth restored with different types of post material. Dental Materials Journal 2006;25 (1):145-150

11. Kazuhiko Okamoto, Teruo Ino, Naoki Iwase, et al. Three-dimensional finite element analysis of stress distribution in composite resin cores with fiber posts of varying diameters. Dental Materials Journal 2008;27(1):49-55.
12. Fu Gang, Du Li, Ren Ai-shu, et al. The three-dimension finite element analysis of stress in posterior residual root restored with different designed post-core crown. West China Journal of Stomatology 2009; 27(1):24-28
13. Fu Gang, Wang Lu, Xia Xi. The three- dimension finite element analys is on stress of different length post of posterior tooth on pos t-core crown. Journal of Chongqing Medical University 2006; 31(4):579-581
14. L in Chuan, Du L I, Shen Jiefei. Construction of three-dimensional finite element models of the first mandibular molar restored with three post and core systems. Pract Stomatol 2008; 24(2):236-239
15. Li Jian, Wu Feng-ming, Fu Xiao-feng, et al. Three-dimensional finite element stress analysis of two forms of post-core restoration of maxillary first molar. Stomatology 2007; 27(5):255-258
16. Jia Jun, Duan Yuan-yuan, Zhou Jian-xue, et al. Three-dimensional finite element stress analysis of all-ceramic crowns of the first mandibular molar. Clin Stomatol 2006; 22(5):266-268
17. Wu Yan-ling, Lu Cheng-lin, Zhang Dong-sheng, et al. Three-dimensional finite element modeling and mechanical analysis of all-ceramic crowns for the first mandibular molar. Chinese Journal of Prosthodontics 2009;10(2):98-100
18. Kazuhiko Okamoto, Teruo ino, Naoki iwase, et al. Three-dimensional finite element analysis of stress distribution in composite resin cores with fiber posts of varying diameters. Dental Materials Journal 2008; 27(1):49-55
19. S Toksavul, M Zor, M Toman, et al. Analysis of dentinal stress distribution of maxillary central incisors subjected to various post-and-core applications. Operative Dentistry 2006;31(1):89-96
20. Zhang Yu-xing, Zhang Wei-hong, Lu Zhi-yue, et al. Fracture strength of custom-fabricated Celay all-ceramic post and core restored endodontically treated teeth. Chinese Medical Journal 2006; 119(21):1815-1820.

10/12/2013