



## KKU Engineering Journal

<https://www.tci-thaijo.org/index.php/east/index>

Published by the Faculty of Engineering, Khon Kaen University, Thailand

### Three dimensional finite element analysis of a mandibular premolar restored with a fiber post and resin composite with different cavity designs

Daraporn Sae-Lee\*<sup>1)</sup>, Teerapan Sosakul<sup>1)</sup>, Watcharin Hovichitr<sup>1)</sup>, Jarupol Suriyawanakul<sup>2)</sup>, Pongsakorn Poovarodom<sup>3)</sup>, Wiphatpong Bumrungsiri<sup>4)</sup>, Somchai Pongkornkumpon<sup>5)</sup> and Wachira Supasatean<sup>1)</sup>

<sup>1)</sup>Department of Prosthetic Dentistry, Faculty of Dentistry, Khon Kaen University, Khon Kaen 40002, Thailand

<sup>2)</sup>Department of Mechanical Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen 40002, Thailand

<sup>3)</sup>Dentist, Kasetwisai Hospital, Roi-et, Thailand

<sup>4)</sup>Dentist, Regional health promotion center 5, Nakhonratchasima, Thailand

<sup>5)</sup>Dentist, Thabo Crown Prince Hospital, Nongkhai, Thailand

Received April 2016

Accepted June 2016

#### Abstract

The stress distribution and fatigue lifetime of an endodontically treated mandibular premolar with various cavity designs for access, restored using a resin composite with and without a fiber post was investigated. A 3D model of a mandibular premolar with one root canal was selected. Eleven study models of tooth structure, including enamel, dentine and pulp tissue, were generated with different cavity designs, i.e., Class I, Class II OM, Class II MOD, Class V, Class V pulp exposure, cortical and cancellous bone, root canal configuration, as well as fiber post. A load of 150 N was applied to the lingual incline plane of the buccal cusp at an angle of 45 degrees to the long axis of the tooth. The results showed that the stress distributions in all models were similar, i.e., the maximum von Mises stresses were observed at the level of the cement-enamel junction (CEJ), and the stress decreased abruptly from the outer to the inner part of the tooth. The maximum von Mises stress along the tooth axis was concentrated at the load-bearing areas, and decreased gradually from the coronal region to the apex of the root. The fatigue lifetimes of the models restored with a fiber post were greater than those without a fiber post.

Keywords: 3D Finite element method, Premolar, Fiber post, Cavity design

#### 1. Introduction

Although the restoration for endodontically treated teeth can be fabricated by many methods, restoration by post and core with crown has been suggested as a gold standard of treatment, with survival rate of 92.2 % after 10 years in service [1]. However, due to the high expense and the limitation of time, the patient may prefer to have a tooth extraction to get rid of their pain, or undergo only root canal treatment and restore with amalgam or composite filling rather than choosing an endodontic treatment follow by the restoration of post and core with crown [2]. Since there are some drawbacks of root canal treated teeth with filling materials, i.e., crown or root fracture often occurs due to a loss of tooth structure by dental carries, non-carries cervical lesion, restorative and root canal treatment procedures, e.g., the access preparation and mechanical instrumentation [3]. All of the reasons mentioned above have led to a decrease in the remaining coronal tooth, and alternative restoration methods have been proposed in many studies. In 2010 Nam et al., studied the mandibular premolar restoration by fiber-reinforced composite post in vivo. The results demonstrated that the post group had a higher fracture resistance than the no post group, and the photoelastic stress distribution

demonstrated a high stress concentration along the root canal space in the no post group, whereas the stress seemed to be distributed in the post group [4]. This finding corresponded with the study by Nothdarft et al. in 2008. They found that the premolar restored with a fiber post had a higher fracture load than without a post. On the other hand, the in vivo study by Kivanc et al. in 2010 reported the fracture resistance of a maxillary premolar with one remaining wall [5] and an in vitro study by Chanatapaporn et al. in 2014 studied a mandibular premolar with cavity class I, class II and class V defect restored with or without a fiber post and resin composite [6]. The results of both studies were similar, i.e., the endodontically treated teeth restored with or without a post combined with resin composite, had different fracture resistances, but the statistics were not significant ( $p < 0.05$ ) [5-6]. In the clinical study by Mannocci et al. in 2002, they compared the success rate of endodontically treated premolar restored with different methods after 3 years in service. The results showed the success rate of endodontically treated premolar restored with a fiber post and direct composite restoration were equivalent to a treatment of full coverage with metal-ceramic crowns [7]. This agreed with Cagidiaco et al. in 2007, who reported a similar survival rate between crown and direct composite restoration after 2 years of usage

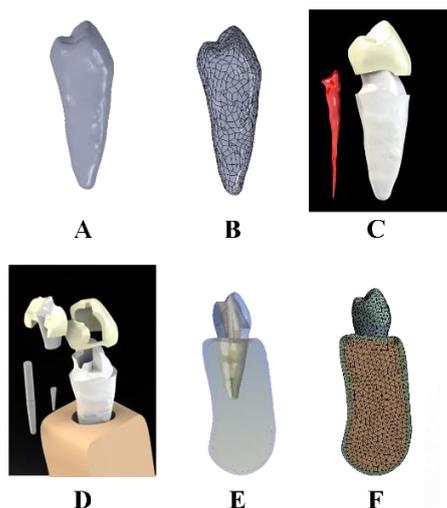
\*Corresponding author. Tel.: +66 4320 2405 ext. 45170

Email address: darsae@yahoo.com

doi: 10.14456/kkuenj.2016.28

[8]. Thus, the results obtained from in vitro and in vivo studies gave conflicting results, which may be due to the differences in sample size, variation of morphology of teeth, magnitude and direction of loading force etc. Hence, the conclusion for an alternative treatment for endodontically treated teeth is still unclear [9].

Recently, computer hardware and technology have developed rapidly and have been applied into many fields of research [10]. Finite element analysis (FEA) has been widely introduced to solve engineering and scientific problems. The first publishing of FEA articles was reported by Courant in 1942 [11], and in the early 1960s it was applied to solve aircraft and space problems. Later on, FEA was used as a tool for study in many fields, i.e., heat transfer, fluid analysis, mass transfer and electromagnetic problems [10], which can reduce the defects and improve the strengths of products. FEA provides many advantages, e.g., it can simulate complex structural models and materials, reducing costs and time. Moreover, FEA can solve many biomedical problems and enhance understanding of oral biomechanical aspects [12-13]. In dentistry, FEA was introduced to study biomechanical properties of different restoration methods. Three dimensional (3D) FEA has been accepted for the investigation of complex structures, and it provides more reliable and accurate results than 2D FEA [14]. According to literature reviews, there are many studies that have used 3D-FEA to evaluate stress distribution and fatigue life time in endodontically treated teeth with different restoration methods [15-17]. Several researchers have studied the maximum stress in endodontically treated teeth with different materials for the post or restoration with a crown [16, 18-19]. The results showed a fiber post can reduce the maximum stress at apical areas, which can reduce the incidence of apical root fracture when compared to a metal post [18-21]. However, there were a few studies of stress distribution in endodontically treated teeth with a fiber post and composite filling. Thus, the aim of this study was to indicate the potential of using a fiber post, in combination with resin composite, as an alternative treatment for restoring endodontically treated teeth.



**Figure 1** The process of creating experimental models : (A) Scanning 3D images of lower premolar, (B) 3D model after primary meshing, (C) Creation of internal structures by Solid Works program, (D) Model components (enamel, dentin, bone, composite resin, fiber post, gutta percha and resin cement), (E) Assembling of complete model before final meshing, (F) Model after the final meshing.

## 2. Materials and methods

### 2.1 Tooth selection for a sample

An extracted mandibular premolar tooth with one root canal, straight root form, root completely mature, without abrasion, crack, caries or any restoration, was selected as a sample.

### 2.2 3 D model preparation

The selected tooth was scanned (Delcam, iMetric D62) for a 3D model file (.stl), which contained data of the external surface of a model (Figure 1).

### 2.3 Internal tooth structure reproduction

The 3D model file was imported into the “Solidworks” program (Solidworks version 2011 Dassault System, France) for initial meshing construction (Figure. 1B). After that, reconstruction of enamel, dentine and dental pulp was performed in accordance with the information by the study of Chun et al. in 2006 [22] (Figure 1C). All data was saved into a .SLDASM filename.

### 2.4 Models assembly

Models with different cavity design, i.e., Class I, Class II OM, Class II MOD, Class V, Class V pulp exposure (Figure 2) were created. Later on, bone model, i.e., cortical and cancellous bone were created, based on the dimensions from study by Katranji et al. in 2007. The root canal was then reproduced to a completed step back preparation shape with an apical constriction size that was equal to main cone No.40. The fiber post model ( Tenax® Fiber trans, Coltene Whaledent, Germany) was also created with diameter 1.3 mm. and length 15 mm. After that all components were assembled (Figures 1D and 1E). The bone level is located 2 mm. lower than the cemento-enamel junction. A total of 11 models were created (Table 1) and all data was saved into .XT files.

### 2.5 Models meshing

The assembled models were transferred from Solid work program to Ansys program ( ANSYS Inc. , USA). The specification of mechanical properties of each model component was assigned (Table 2) and all components were assumed to be homogeneous with isotropic and linear elastic behavior. The stress life graph of dentine (S-N curve) was assigned in accordance to the study by Singh et al. in 2010 (Figure 3). After that the mesh independence method was used and the result showed that the suitable element size was 0.8 mm. The model was meshed with the tetrahedron method. The number of all elements was approximately 140,000 elements, with approximately 200,000 nodes (Figure. 1F).

### 2.6 Boundary and loading conditions

In this study, it was assumed that all components were homogeneous with isotropic and linear elastic behavior, so the contact behavior of all components was indicated as “bond”. A load with a magnitude of 150 Newtons, which represents the normal chewing force [23], was applied on the lingual incline plane of the buccal cusp (5 square millimeter of semicircle area) in every model at an angle of 45 degrees

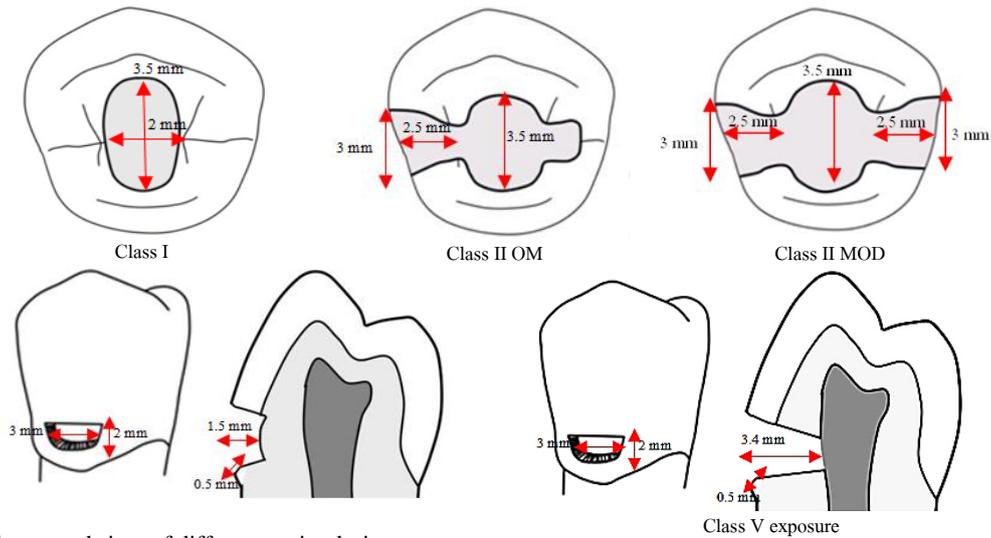


Figure 2 Shapes and sizes of different cavity designs.

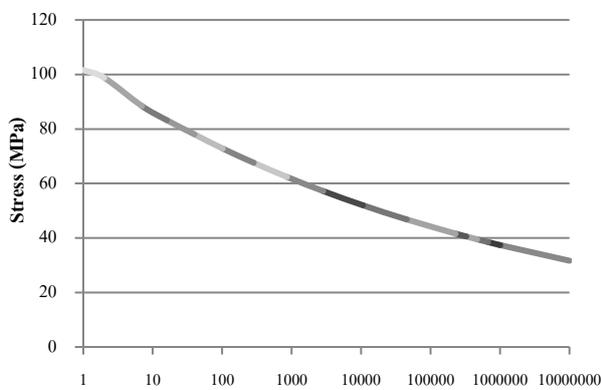


Figure 3 Stress-life graph of dentine (S-N curve).

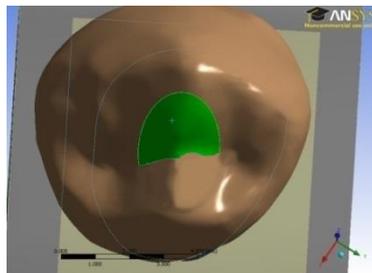


Figure 4 Loading area in half circular shape on lingual inclines plane of buccal cusp.

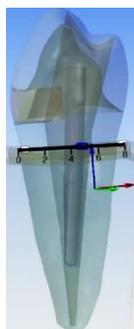


Figure 5 The von Mises stress distribution at cervical level, along the imaginary line which originated from buccal to lingual surface.

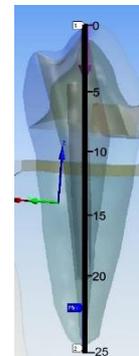


Figure 6 The von Mises stress distribution along the imaginary line which originated from the tip of the buccal cusp to the apex of the root.

to the long axis of the model (Figure 4). Each model was fixed at the mesial and distal surface of the bone. The analysis of von Mises stress and the fatigue life criteria that was used in this study was “Goodman theory”.

### 3. Results

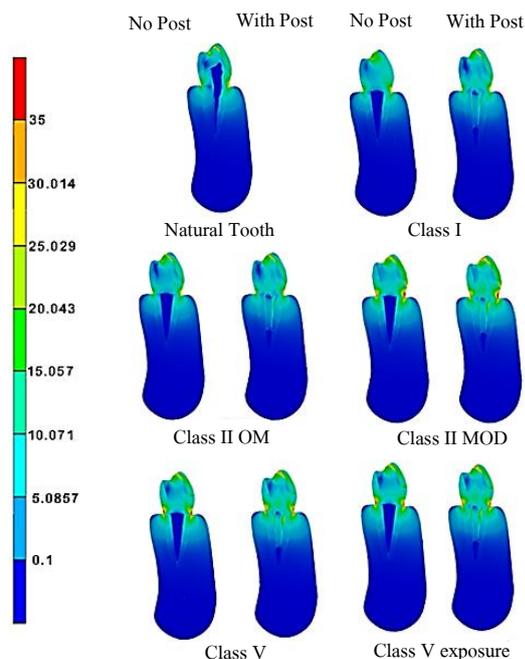
#### 3.1 The von Mises stress distribution

The von Mises stress distribution along the imaginary line which originated from buccal to lingual surface (Figure 5) and from the tip of the buccal cusp to the apex of the root (Figure 6) were analyzed.

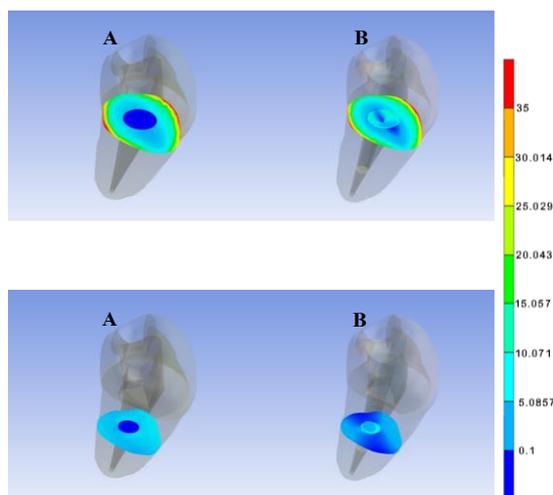
The results showed that the stress distribution in all models were similar, i.e., the maximum von Mises stresses were observed at the cement-enamel junction level (CEJ) (Figure 7), and the stress decreased abruptly from the outer to the inner part of the root (Figure 8). When considering along the axis of the root, the maximum von Mises stress was concentrated at the load-bearing areas and the stress decreased gradually from the coronal part to the apex of the root.

##### 3.1.1 The stress distribution in bucco-lingual direction at the cervical level

The stress was concentrated at the buccal and lingual surface in all models, especially class II MOD, class V and class V pulp exposure (Figure 7). When investigating every



**Figure 7** Von Mises stress distribution of each model.



**Figure 8** Cross-sectional image of von Mises stress distribution at cervical level of the tooth (upper) and at middle level of the root (lower), (A) No post and (B) With post.

**Table 1** Models with different cavity preparations

Model	Cavity preparation	Tenax® Fiber trans post
1	Natural tooth	-
2	Class I	No
3	Class I	Yes
4	Class II OM	No
5	Class II OM	Yes
6	Class II MOD	No
7	Class II MOD	Yes
8	Class V	No
9	Class V	Yes
10	Class V pulp exposure	No
11	Class V pulp exposure	Yes

**Table 2** Mechanical properties of materials in this study

Materials	Elastic modulus (GPa)	Poisson's coefficient
Enamel	84.1 <sup>a</sup>	0.20 <sup>a</sup>
Dentine	18.6 <sup>a</sup>	0.31 <sup>a</sup>
Pulp	2 <sup>a</sup>	0.45 <sup>a</sup>
Cortical bone	14.7 <sup>a</sup>	0.30 <sup>a</sup>
Cancellous bone	1.37 <sup>a</sup>	0.30 <sup>a</sup>
Composite filling (Filtek™ Z350, 3M ESPE, USA)	11.35 <sup>b</sup>	0.30 <sup>b</sup>
Resin cement (Panavia™ F2.0, Kuraray, JAPAN)	60 <sup>c</sup>	0.30 <sup>c</sup>
Gutta-percha	0.69x10 <sup>-3 a</sup>	0.45 <sup>a</sup>
Tenax® Fiber trans, Coltene Whaledent, Germany	26 <sup>d</sup>	0.30 <sup>d</sup>

References <sup>a</sup> Chun et al. [22]

<sup>b</sup> Manufacturer's data of Filtek™ Z350, 3M ESPE, USA

<sup>c</sup> Manufacturer's data of Panavia™ F2, Kuraray, JAPAN

<sup>d</sup> Manufacturer's data of TENAX® Fiber Trans, Coltène, FRANCE

model without a post, the stress was not distributed to the center of the model (Figure 8A upper). But in every model with a post, a pattern of stress distribution into the center of the model was exhibited (Figure 7 and 8B upper). The line graph of von Mises stress obtained in the bucco-lingual direction at the cervical level (Figure 9) showed a trend of stress decreasing which occurred abruptly in the center part of all models, whereas in the models with a post, they showed a stress distribution continuity from the buccal side to the lingual side.

### 3.1.2 The stress distribution along the tooth axis from the load bearing area through apex

According to Figure 7, a stress distribution was observed along the tooth axis from the load bearing area through the apex. The stress in all models with a post was distributed into the middle part of the root, but in the models without a post, the stress was distributed only at the cervical level (Figure 8A and B lower). The line graph of von Mises stress obtained along the lines from the tip of the buccal cusp to the apex of the root (Figure 10) illustrates that the stress distribution has a tendency to decrease gradually from the upper to the lower part of the model. However, in models with a post, the stress distribution continues along the axis of the model, whereas in the models without a post, the stress distribution goes down through to only the cervical area (about 10 mm. down from the occlusal plane).

### 3.2 The maximum von Mises stress

#### 3.2.1 The maximum von Mises stress at the cervical level

The maximum stress at the cervical level for each model is shown in Figure 11. The maximum stress in the models with a post (1, 2 and 4) is lower than the models without a post (6, 8 and 10) in every cavity design. Model number 10 exhibited the highest maximum stress and model number 4 showed the lowest maximum stress.

#### 3.2.2 The maximum von Mises stress at load bearing area

The maximum stress at the load bearing area in each model is shown in Figure 12. The maximum stress of model without a post was found highest in model number 1,

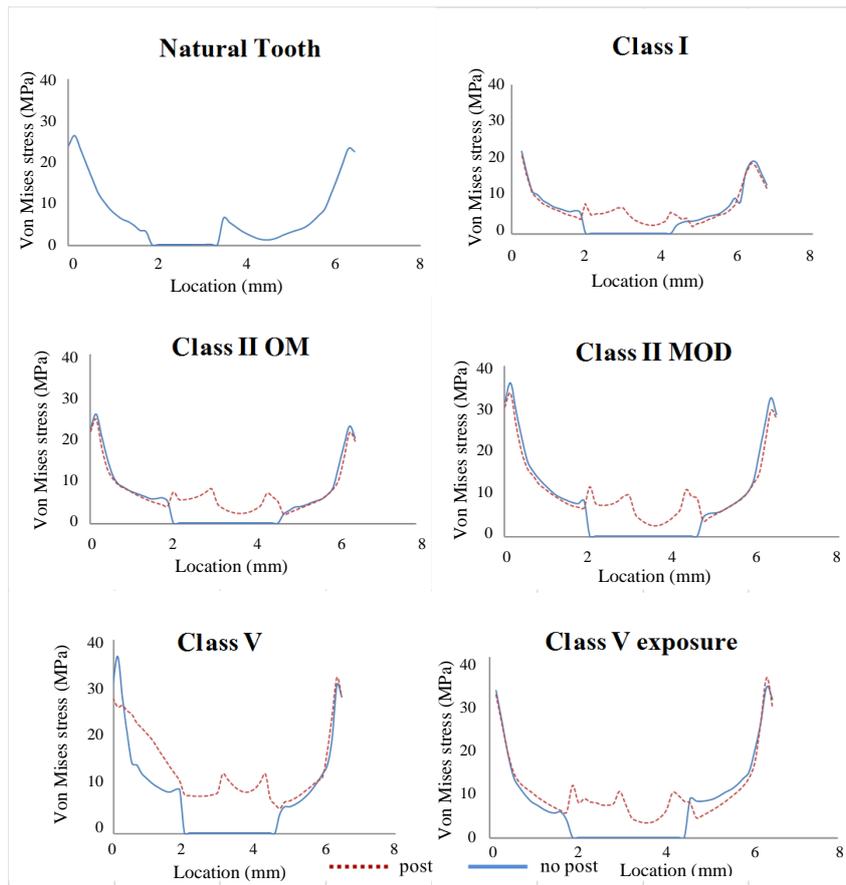


Figure 9 Line graph of the von Mises stress obtained in the bucco-lingual direction at the cervical level.

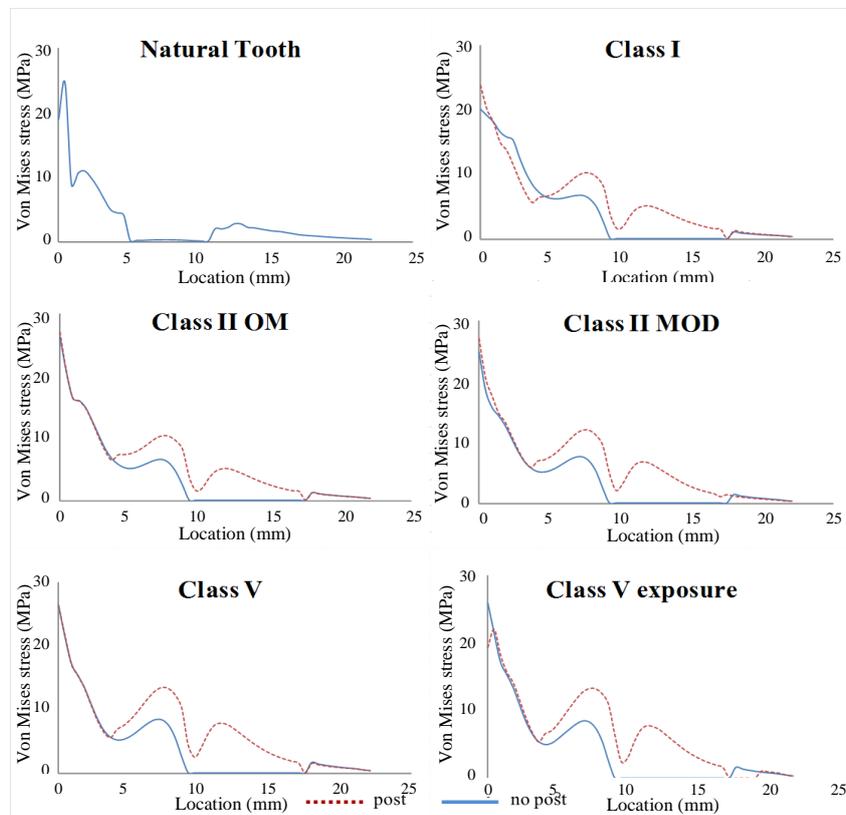
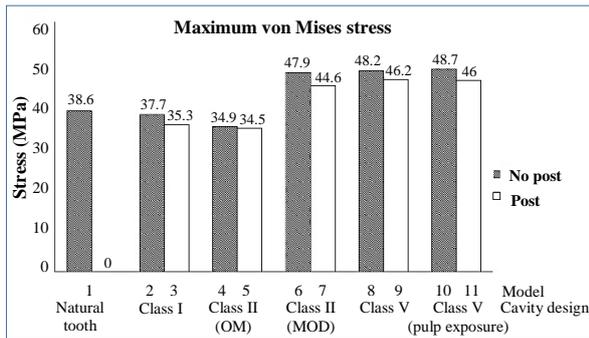
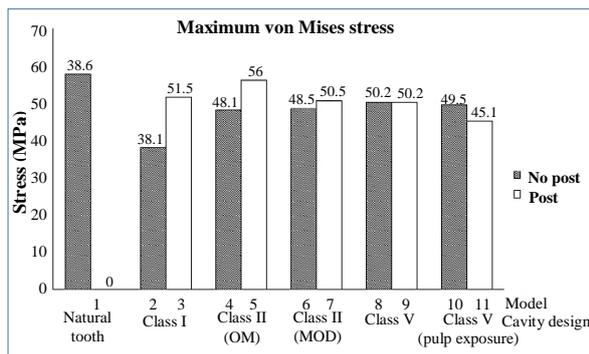


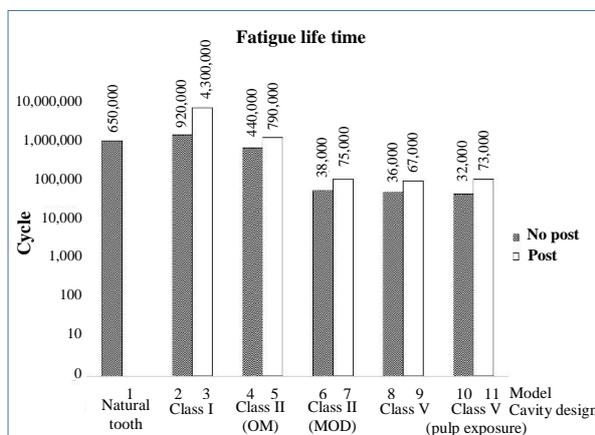
Figure 10 Line graph of the von Mises stress obtained along the lines from the tip of the buccal cusp to the apex of the root.



**Figure 11** Column graph of maximum equivalent stress at the cervical area.



**Figure 12** Column graph of maximum equivalent stress at the loading areas.



**Figure 13** Column graph of fatigue life time in experimental models with different cavities.

followed by models number 8, 10, 6 and 4, respectively and model number 2 showed the lowest maximum stress. The maximum stress in the models class I, II (OM) and II (MOD) with a post were higher than the models without a post. The maximum stresses in models class V with a post or without a post were equal. Interestingly, in the model class V pulp exposure with a post, the stress was lower than the model without a post.

### 3.3 Fatigue life time

Among the models without a post, the fatigue life time results of the models 1, 2 and 4 were greater than the models 6, 8 and 10 (Figure 13). And the fatigue life time of model number 2 was the highest, whereas model number 10 had the

lowest value. When comparing the fatigue life time obtained from the same cavity design, the model with a post had a longer fatigue life time than the model without a post.

## 4. Discussion

The stress distribution and fatigue life time of an endodontically treated lower premolar which has been restored by resin composite combined with or without a post was analyzed using 3D FEA. This method has been used in order to reduce the time and cost of the experiment. Moreover, different testing materials could also be controlled and the testing method could be performed in different ways. However, the obtained results could be applied to only the lower premolar or another tooth which has similar dimensions. Finite element analysis can be done in either 2D or 3D, which may affect the outcome results for each situation, i.e., Sorrentino et al. in 2007 used 3D FEA to study strain and stress distributions in endodontically treated maxillary central incisors restored with different posts, core and crown materials. The results showed stress concentrations in the cervical area, but there were a few stress concentrations at the apical area [19], which was similar to this study. On the other hand, in previous studies by Pegoretti et al. in 2002 and Coelho et al. in 2009 which 2D FEA was used to evaluate the stress distribution in endodontically treated teeth, the stress concentration was found along the post surface [20, 24]. Thus, different results between 2D and 3D FEA may occur because the 3D FEA includes the third axis (z axis) for analysis, hence the stress distribution is more likely to reflect natural behavior [14].

Moreover, the result of the FEA may depend on the components of model, e.g., the periodontal ligament (PDL). Several studies that addressed the model with PDL have shown a stress concentration at the cervical and apical area [16, 24-25]. In contrast, the stress in models without PDL, is concentrated only in the cervical area. This difference may be due to the limitation of movement in the model without PDL, whereas the model with PDL could move within the PDL space during the load application. However, according to Bessine and Fernandez in 2010 the PDL has no effect on the stress distribution [17]. And Sorrentino et al. in 2007 reported that the force direction could be inaccurate in the model with PDL [19]. Therefore, the PDL was excluded in all models in this study to reduce the errors. The fixed position of the model may be another factor that can have an effect on the stress distribution. Li et al. in 2008 fixed a support model at the base area, and the results show that the stress concentration at the apical area was more than in this study, in which the support model was fixed at both sides (mesial and distal area). The stress concentration that occurred at the apical area, may have arisen from the reaction force through the long axis of the tooth when the model was fixed at the base [16]. According to the review of literatures on 3D FEA in endodontically treated teeth restoration with different post materials, restoration with a fiber post has a stress concentration at the cervical and load bearing areas. However, the stress was distributed into the tooth more equally in all directions when compared to the model with the cast metal post, in which the stress was concentrated only at the apical area and post dentine interface [20, 21, 26]. Clinical studies have also reported a higher fracture incidence of endodontically treated teeth at the apical area if the tooth was restored with a cast metal post, hence the failure of endodontically treated teeth that were restored with a fiber posts may decrease [27]. In correspondence with this study, models with a fiber post showed a stress distribution

along the long axis of tooth and the stress had a tendency to decrease from the upper to the lower part of the root. Moreover, the stress distribution in the bucco-lingual direction at the cervical level had a tendency to decrease from the outer to the inner parts. Thus, the tooth restored with a fiber post may decrease the risk of root fracture [21, 26]. The in vitro study by Nam et al. in 2010 and Northdarft et al. in 2008 also reported similar findings. The fractural strength of the tooth restored with a fiber post and resin composite increased significantly ( $p$ -value  $> 0.05$ ), except in the tooth without the remaining wall [4, 28]. Thus, the tooth restored with a fiber post and resin composite could be an alternative treatment to restore an endodontically treated teeth.

The fracture of a tooth structure and restorative material may not occur from a high chewing force at one time, but it may be fractured by receiving a dynamic load, and then it undergoes fatigue and ultimately fractures [29-30]. Therefore, this study evaluated the effect of dynamic loading on the tooth structure. The results showed that the fatigue life times of endodontically treated teeth restored with a post were higher than groups without a post. This finding corresponds with the in-vitro study by Sahafi et al. in 2005 which a dynamic load of 600 N with a frequency of two rounds per second was applied to endodontically treated teeth restored with a fiber post and metal crown. The results reported that the fracture resistance increased significantly in every sample ( $p$ -value  $> 0.05$ ) [31].

When the remaining wall was absent, it may affect the fatigue life time in every model. In model class II (MOD), the fatigue life time was less than model class I and class II (OM). In addition, the model with cervical lesion such as model class V and class V pulp exposure had the least fatigue life time, which may be due to a high stress concentration at the cervical level. A similar finding was reported by Ausiello et al. in 2011. The in vitro study found that the fracture often occurred around the high stress concentration area. The number of cycles that led to fracture in molar class II (MOD) group was  $10^4$  cycles, which was similar to this study, i.e., the fatigue life time of model premolar class II (MOD) group was  $7.5 \times 10^4$  cycles [32]. However, in this study an endodontically treated lower premolar was used for the stimulation, while in their study, a lower molar was used. However, the loading force that they applied was 4 times higher than this study, which may result in the similar finding. In order to compare the fatigue life time results, more factors, i.e., shape of the tooth, vitality of tooth, restoration method, loading force magnitude and direction, need to be considered. It has been noticed in this study that the natural tooth model had less fatigue life time than the class I model. This could occur as a mechanical property of the model components such as gutta percha and resin composite in class I model were similar with dentine. Therefore, the stress could be distributed along the axis better than in a natural tooth. The dental pulp which has a delicate mechanical property could not enhance the stress distribution. This finding was supported by the in vitro studies of Pegoretti et al. in 2002 and Zarone et al. in 2006 [13,20] which should be furthered investigated.

## 5. Conclusions

The stress distributions in all models were similar, i.e., the maximum von Mises stresses were observed at the level of the cement-enamel junction (CEJ) and the stress decreased abruptly from the outer to the inner part of the root. When considering along the axis of the root, the maximum von Mises stress was concentrated at the load-bearing areas and

the stress decreased gradually from the corona to the apex of the root. This study may indicate a potential method for restoring endodontically treated teeth using a fiber post in combination with resin composite, since fatigue life time could be increased because the fiber post can distribute the stress both along the longitudinal and horizontal axis of the tooth. However more clinical studies are needed in the future.

## 6. Acknowledgements

The researchers would like to express their sincere thanks to the Faculty of Dentistry, Khon Kaen University for the supportive research fund and the Faculty of Engineering, Thammasat University for supporting with a Solidwork software license. In addition, we are grateful for the advice of colleagues in the Research Unit on Mechanical Component Design, Mechanical Engineering, Khon Kaen University, Mr. Ponthep Vengsungnle and Mr. Kantinan Phuekpan, for their suggestions and all their help.

## 7. References

- [1] Dammaschke T, Steven D, Kaup M, Ott KH. Long-term survival of root- canal- treated teeth: a retrospective study over 10 years. *J Endod.* 2003;29(10):638-43.
- [2] Division DH. 7th National oral health survey of Thailand report. Bangkok: WVO Office of Printing Mill; 2007.
- [3] Perdigao J, Gomes G, Augusto V. The effect of dowel space on the bond strengths of fiber posts. *J Prosthodont.* 2007;16(3):154-64.
- [4] Nam SH, Chang HS, Min KS, Lee Y, Cho HW, Bae JM. Effect of the number of residual walls on fracture resistances, failure patterns, and photoelasticity of simulated premolars restored with or without fiber-reinforced composite posts. *J Endod.* 2010;36(2):297-301.
- [5] Kivanc BH, Alacam T, Gorgul G. Fracture resistance of premolars with one remaining cavity wall restored using different techniques. *Dent Mater J.* 2010;29(3):262-7.
- [6] Chanatapaporn P, Sae-Lee D, Somreunsan K, Paimsakul N, Yamngam T. Fracture resistance of endodontically treated mandibular premolar and with proximal caries or non-carious lesion restored using composite resin with or without fiber post. *Khon Kaen Uni Dent J.* 2014;17(1):33-47. [In Thai].
- [7] Mannocci F, Bertelli E, Sherriff M, Watson TF, Ford TR. Three-year clinical comparison of survival of endodontically treated teeth restored with either full cast coverage or with direct composite restoration. *J Prosthet Dent.* 2002;88(3):297-301.
- [8] Cagidiaco MC, Radovic I, Simonetti M, Tay F, Ferrari M. Clinical performance of fiber post restorations in endodontically treated teeth: 2- year results. *Int J Prosthodont.* 2007;20(3):293-8.
- [9] 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(4):442-8.
- [10] Geng JP, Tan KB, Liu GR. Application of finite element analysis in implant dentistry: a review of the literature. *J Prosthet Dent* 2001;85(6):585-98.
- [11] Pelosi G. The finite-element method, part I: R. L. Courant: historical corner. *IEEE Antenn Propag Mag.* 2007;49(2):180-2.

- [12] Piccioni MARV, Campos EA, Saad JRC, Andrade MFd, Galvão MR, Rached AA. Application of the finite element method in Dentistry. *RSBO*. 2013;10:170-7.
- [13] Zarone F, Sorrentino R, Apicella D, Valentino B, Ferrari M, Aversa R, et al. Evaluation of the biomechanical behavior of maxillary central incisors restored by means of endocrowns compared to a natural tooth: a 3D static linear finite elements analysis. *Dent Mater* 2006;22(11):1035-44.
- [14] Romeed SA, Fok SL, Wilson NH. A comparison of 2D and 3D finite element analysis of a restored tooth. *J Oral Rehabil*. 2006;33(3):209-15.
- [15] Gurbuz T, Sengul F, Altun C. Finite element stress analysis of short-post core and over restorations prepared with different restorative materials. *Dent Mater J*. 2008;27(4):499-507.
- [16] Li Xn, Shi YK, Li ZC, Song CY, Chen XD, Guan ZQ, et al. Three-dimensional finite element analysis of a maxillary central incisor restored with difference post-core materials. *Int Chin J Dent*. 2008(8): 21-7.
- [17] Bessine L, Fernandez BEJ. Evaluation of different post systems : finite element method. *Int J Odontostomat*. 2010;4(3):229-36.
- [18] Okamoto K, Ino T, Iwase N, Shimizu E, Suzuki M, Satoh G, et al. Three-dimensional finite element analysis of stress distribution in composite resin cores with fiber posts of varying diameters. *Dent Mater J*. 2008;27(1):49-55.
- [19] Sorrentino R, Aversa R, Ferro V, Auriemma T, Zarone F, Ferrari M, et al. Three-dimensional finite element analysis of strain and stress distributions in endodontically treated maxillary central incisors restored with different post, core and crown materials. *Dent Mater*. 2007;23(8):983-93.
- [20] Pegoretti A, Fambri L, Zappini G, Bianchetti M. Finite element analysis of a glass fibre reinforced composite endodontic post. *Biomater*. 2002;23(13):2667-82.
- [21] 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(1):145-50.
- [22] Chun KJ, Li HJ. A study on the external and internal morphology of the mandibular first premolar using a Micro-CT. *Key Eng Mater*. 2006;321-323: 1139-44.
- [23] Anderson DJ. Measurement of stress in mastication. I. *J Dent Res*. 1956;35(5):664-70.
- [24] Coelho CS, Biffi JC, Silva GR, Abrahao A, Campos RE, Soares CJ. Finite element analysis of weakened roots restored with composite resin and posts. *Dent Mater J*. 2009;28(6):671-8.
- [25] Maceri F, Martignoni M, Vairo G. Mechanical behaviour of endodontic restorations with multiple prefabricated posts: a finite-element approach. *J Biomech*. 2007;40(11):2386-98.
- [26] Sethuraman R. The effect of three post and core systems on the stress distribution in endodontically treated teeth - a two dimensional finite element analysis. *J Adv Dent Res*. 2011;2(1):41-50.
- [27] Hayashi M, Takahashi Y, Imazato S, Ebisu S. Fracture resistance of pulpless teeth restored with post-cores and crowns. *Dent Mater*. 2006;22(5):477-85.
- [28] Nothdurft FP, Seidel E, Gebhart F, Naumann M, Motter PJ, Pospiech PR. The fracture behavior of premolar teeth with class II cavities restored by both direct composite restorations and endodontic post systems. *J Dent*. 2008;36(6):444-9.
- [29] Papadogiannis Y, Lakes RS, Palaghias G, Helvatjoglou-Antoniades M, Papadogiannis D. Fatigue of packable dental composites. *Dent Mater*. 2007;23(2): 235-42.
- [30] Ali SA, Manoharan PS, Shekhawat KS, Deb S, Chidambaram S, Konchada J, et al. Influence of Full Veneer Restoration on Fracture Resistance of Three Different Core Materials: an in vitro study. *J Clin Diagn Res*. 2015;9(9):ZC12-5.
- [31] Sahafi A, Peutzfeldt A, Ravnholt G, Asmussen E, Gotfredsen K. Resistance to cyclic loading of teeth restored with posts. *Clin Oral Investig*. 2005;9(2):84-90.
- [32] Ausiello P, Franciosa P, Martorelli M, Watts DC. Numerical fatigue 3D-FE modeling of indirect composite-restored posterior teeth. *Dent Mater*. 2011;27(5):423-30.