

# The Comparison of The Micro Push-Out Bond Strength of AH Plus, Endosequence BC, and MTA Fillapex Sealers: A Laboratory and Finite Element Analysis Study

Tanintaraarj P\* Nguyen TQ\*\* Pholdee N\*\*\* Jainaen A\*\*\*\*

## Abstract

This laboratory study aimed to evaluate the micro push-out bond strength of 3 sealers: AH Plus, Endosequence BC, and MTA Fillapex. The Finite Element Analysis (FEA) was built and estimated micro push-out bond strength to the laboratory. Thirty extracted single-rooted lower premolars were instrumented and divided into 3 groups. All root canals were obturated by warm vertical compaction technique using a match gutta-percha cone and 3 different sealers: AH Plus, Endosequence BC, and MTA Fillapex (n=10 roots/group). After 2 weeks incubation at 37°C and 100% humidity, three slices of 1±0.1 mm-thickness were cut 3 locations: coronal, middle and apical, for the push-out bond strength test. The failure mode of the sample was examined under 10x magnification. Three samples size 2x2x25 mm of each sealer were prepared and tested for modulus of elasticity, and then the FEA results analysis was created under ANSYS workbench. The micro push-out bond strength was analyzed using one-way ANOVA, and the correlation between the laboratory and FEA was evaluated by the Pearson correlation test. The significance was set at  $p < 0.05$ . Results of the laboratory test showed that AH Plus and Endosequence BC sealers had a superior micro push-out bond strength compared to the MTA Fillapex sealer ( $p < 0.001$ ), but there was no statistically significant difference between the AH Plus and the Endosequence BC sealer ( $p > 0.05$ ). For the FEA, AH Plus presented the highest maximum micro push-out bond strength at the coronal dentine, followed by Endosequence BC and MTA Fillapex sealer (2.48, 2.16 and 1.23 MPa, respectively). The same results were found at middle dentine (2.19, 2.09 and 0.70 MPa, respectively), and at apical dentine (1.72, 1.63 and 0.43 MPa, respectively). The micro push-out bond strength from the laboratory and FEA had highly positive relationship ( $r = 0.869$ ). In conclusion, Endosequence BC exhibited a micro push-out bond strength comparable to AH Plus, surpassing MTA Fillapex sealer. The FEA test presented a highly positive correlation in micro push-out bond strength with laboratory testing.

**Keywords:** Calcium silicate-based sealer/ Epoxy resin-based sealer/ Finite element analysis/ Micro push-out bond strength/ Root canal sealer

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## Introduction

The primary purposes of endodontic treatment are to eliminate and prevent infection of the root canal system, which depends on debridement, shaping and obturation procedures. Gutta-percha cones are the first choice as filling material due to their suitable physical, chemical, and biological properties. However, gutta-percha does not bond to the root dentine, which works as a piston to pull sealer into the small and irregular spaces of the root canal system and attach to the root dentine surface.<sup>1</sup> AH Plus is an epoxy resin-based sealer, which has been widely used and considered the

standard sealer.<sup>2,3</sup> AH Plus bonds to radicular dentine by forming a covalent bond with the collagen matrix.<sup>4,5</sup> However, the moist environment of the root canal will affect the setting process, hence, the bond strength of AH Plus to the dentine wall will be decreased.<sup>6,7</sup> The calcium silicate-based sealers have been developed to overcome the moist environment of the root canal. Endosequence BC™ (Brasseler, Savannah, GA, USA) and MTA Fillapex (Angelus, Londrina, PR, Brazil) are two of the most famous calcium silicate-based sealers in dental market. They presented an

\* Dental Department, Kaeng Khoi Hospital, Amphur Kaeng Khoi, Saraburi.

\*\* Faculty of Dentistry, Tra Vinh University, Tra Vinh, Viet Nam.

\*\*\* Sustainable and Infrastructure Research and Development Center, Department of Mechanical Engineering, Faculty of Engineering, Khon Kaen University, Amphur Muang, Khon Kaen.

\*\*\*\* Department of Restorative Dentistry, Faculty of Dentistry, Khon Kaen University, Amphur Muang, Khon Kaen.

excellent flowing ability, releasing calcium ions and bonding to the dentine by a biomineralization process.<sup>8</sup> Therefore, it is essential to compare the adhesion of these sealers to radicular dentine, which will provide new information for clinical choice.

The micro push-out test is a modification method that evaluates the bond strength of root canal filling materials. In this method, a loading force is applied on the root canal filling materials through a plunger until the dislodgement occurs.<sup>9</sup> The plungers are placed on the center of root canal filling specimen, without making contact with the dentine wall. This method allows for evaluating the bond strength of the root canal filling materials and the failure mode of the bonding interface.<sup>10,11</sup> However, the micro push-out bond strength test can be affected by various factors, including root canal anatomy, plunger diameter and sample thickness.<sup>9,11</sup> In order to minimize the factors that affect the micro-push out test in individual tooth samples, the micro-computer is involved in tooth model creation for the Finite Element Analysis (FEA). FEA is an engineering method that is used to determine the stress distribution when a force is applied to a structure by the numerical analysis of complex structures based on their material properties. The fundamental principle of FEA involves dividing the problem domain into elements and connecting each element through a node.<sup>12</sup> FEA analysis is performed by creating a mesh that contains millions of small elements to form the shape of a structure.<sup>13</sup> For the study of root canal therapy, FEA simulates and analyzes the stress within the root canal and on the root canal wall.<sup>14</sup> FEA was also reported to simulate a push-out test by established 3 parameters: the diameter of the pin, the specimen's thickness, and the elastic modulus of the intracanal filler.<sup>9</sup>

This study aimed to determine the micro push-out bond strength of AH Plus, Endosequence BC, and MTA Fillapex to root dentine and evaluate the relationship between the laboratory and the FEA test. The null hypotheses tested were: (i) There was no difference in the micro push-out bond strength of three experimental sealers; (ii) There was no

correlation between the laboratory and the FEA test for micro push-out bond strength.

## Materials and methods

### Sample of study

Thirty-extracted lower premolar teeth with a length of at least 15 mm from Cemento-Enamel Junction (CEJ) to the root apex were used. After extraction, the teeth were stored in 0.1% thymol solution for disinfection. Then, the teeth were radiographed in mesiodistal and buccolingual directions to evaluate root canal curvature. Roots with a single-rooted canal and a curvature less than 5° according to Schneider's method were included.<sup>15</sup>

### Instrumentation and obturation

The crowns were transversely sectioned 2 mm below the CEJ with a diamond saw (Isomet 1000, Buehler, Lake Bluff, NY, USA) at low speed under copious water cooling. To determine the working length, a K-file no.20 (SybronEndo, Orange, CA, USA) was inserted into the root canal until the tip of the file was observed at the apical foramen. The file was removed from the root canal, and the length of the file was measured using an endodontic ruler. Then, the working length was determined by subtracting 1 mm from the file's length. Thirty canals were prepared by WaveOne™ rotary instrument (Dentsply, Maillefer, Tulsa, Oklahoma, USA) to size 40/08. The canals were irrigated between each file with 5 ml of 2.5% NaOCl. To remove the smear layer, the root canals were irrigated with 5 ml of 17% EDTA followed by 5 ml of 2.5% NaOCl. The teeth were randomly divided into three groups (n=10). Then, the canals were filled using a match gutta-percha cone (Large Wave One™ obturation, Dentsply, Maillefer, Tulsa, Oklahoma, USA) and warm vertical compaction technique with one of 3 kinds of sealer.

Group 1: The canals were obturated by gutta-percha cone and AH Plus™ Jet (Dentsply Maillefer, Tulsa, Oklahoma, USA)

Group 2: The canals were obturated by gutta-percha cone and Endosequence BC™ (Brasseler, Savannah, GA, USA)

Group 3: The canals were obturated by gutta-percha cone and MTA Fillapex (Angelus, Londrina, PR, Brazil)

Sealers were prepared according to manufacturers' instructions. AH Plus™ was mixed using the AH Plus Jet mixing system with the intraoral tip. MTA Fillapex came with auto mix syringe while Endosequence BC™ was a ready mixed sealer (Table 1). The sealer was inserted into the canal using a K-file no.40, the master cone was also lightly coated

with sealer and seated to working length in a slow plunging motion. The main cone was cut until 4 mm left at apical with System B endodontic cordless unit (SybronEndo, Orange, CA, USA) and filled up the rest of the canal with thermoplasticised gutta percha with System B endodontic cordless fill unit (SybronEndo, Orange, CA, USA).

**Table 1** Root canal sealers used in this study, with their respective manufacturer, composition and batch number.

Sealer (Manufacturer)	Composition	Batch number
<b>AH Plus</b> (Dentsply Maillefer, Tulsa, Oklahoma, USA)	Paste A: Bisphenol-F epoxy resin, calcium tungstate, zirconium oxide, silica, iron oxide, pigments Paste B: Dibenzylidiamine, aminoadamantane, tricyclodecanediamine, calcium tungstate, zirconium oxide, silica, silicone oil	0705000020 
<b>Endosequence BC</b> (Brasseler, Savannah, GA, USA)	Zirconium oxide, filler, calcium silicates, calcium phosphate, calcium hydroxide, thickening agents	15223-1 
<b>MTA Fillapex</b> (Angelus, Londrina, PR, Brazil)	Salicylate resin, resin diluent, natural resin, bismuth oxide, silica nanoparticles, MTA, pigments	16832 

### Preparation of samples for micro push-out bond strength testing

After the obturation process, all roots were radiographed at labiolingual and mesiodistal directions to verify the quality of root canal filling. The canal orifices were restored with Cavit (3M ESPE, Seefeld, Germany). All samples were placed at 37°C in 100% humidity for 2 weeks to allow for complete setting of root canal sealers. Then, each root was sectioned perpendicular to the long axis at 2 mm (apical), 7 mm (middle) and 12 mm (coronal) from the apex using a diamond saw (Isomet 1000, Buehler, Lake Bluff, NY, USA) under continuous water cooling. The thickness of the root sections was  $1 \pm 0.1$  mm. Thirty slices per group were tested for micro push-out bond strength.

### The micro push-out bond strength testing

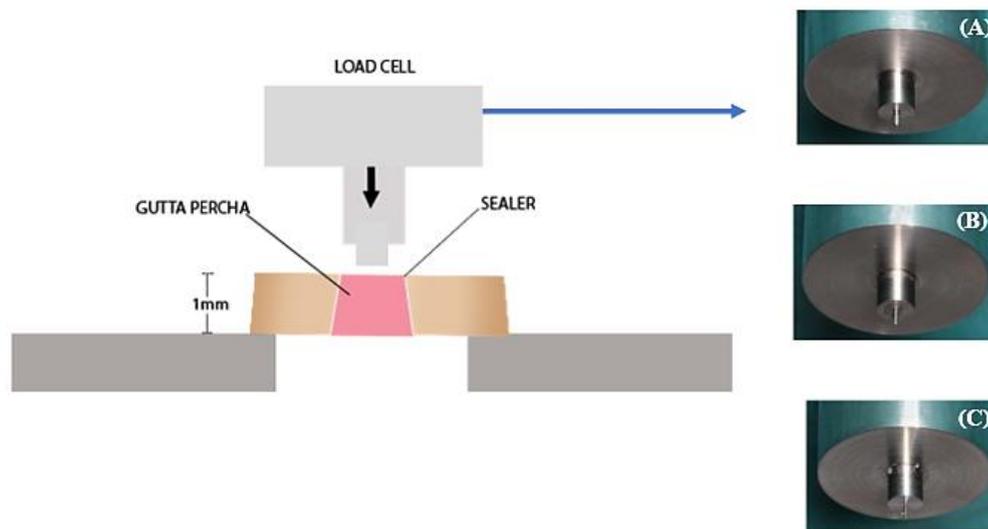
Each root section was mounted on a rigid metal plate with the apical side facing to the plunger. The root canal was centered above an opening hole of the metal plate to allow the filling material to fall from the canal. The micro push-out test was performed by applying a compressive load to the apical side of each section by using plungers. The diameter of plungers was selected according to the root canal diameter of the slice: 0.8 mm for the coronal dentine, 0.5 mm for the middle dentine and 0.3 mm for the apical dentine section (Figure 1). The micro push-out bond strength was measured using a universal testing machine (LR30K, Ametek Inc, Pennsylvania, USA) with a crosshead speed of 0.5 mm/min. The maximum force (F-max) was recorded in Newton (N) and transformed to Mega-Pascal (MPa) according to the following equation:

The micro push-out bond strength (MPa) =  $F_{max}/A$

A was sealer adhesion area in  $mm^2$ , which was calculated using the following equation:

$$A = \pi(R + r) [h^2 + (R-r)^2]^{0.5}$$

$\pi = 3.14$ ; R = radius of the canal in the coronal side; r = radius of the canal in the apical side; h = height of the specimen.<sup>16</sup> The radius of the coronal and apical sides in each specimen was measured under the stereomicroscope (Olympus, Tokyo, Japan).



**Figure 1** The illustration of micro push-out bond strength testing. The root section was affixed onto a rigid metal plate, with the apical side oriented towards the plunger. The plunger was positioned at the center of the root canal (left image). Plunger diameters were chosen as follows: 0.8 mm for coronal dentine (A), 0.5 mm for middle dentine (B) and 0.3 mm for apical dentine section (C) (right image).

After the laboratory test, the root section was evaluated with a stereomicroscope at 10x magnification to detect the failure mode between the filling material and the root canal wall.<sup>17</sup> The failure mode was classified as follows: cohesive, adhesive, or mixed.

- Adhesive: The sealer was totally removed from the root canal dentine wall.

- Cohesive: The fracture occurred within the material, with the sealer covering the dentine.

- Mixed: Mode was a combination of two kinds of failure: adhesive and cohesive.

#### Young's modulus and Poisson's ratio

Nine bar shape specimens were prepared using stainless steel mold with the dimensions 25x2x2 mm according to ISO4049/2000<sup>18</sup> from the AH Plus, Endosequence BC and MTA Fillapex sealer. After specimens were set, they were removed from the mold and stored at 37°C and 95% humidity

for 2 weeks to allow complete setting. The three-point bending test was prepared using the universal testing machine (LR30K, Ametek Inc, Pennsylvania, USA) with a crosshead speed of 0.5 mm/min and the load cell set at 50N for maximum load. The maximum values were recorded in Newton (N), and Young's modulus was determined as follows:

$$E = FL^3/4bH^3d$$

Where F was the maximum load; L was the distance between the support; b was the width of the specimen; H was the height of the specimen; d was the deflection corresponding to load F.<sup>19</sup>

The Poisson's ratio was calculated as the transverse to the longitudinal strain, derived from the model validation from the ANSYS workbench program in FEA.

### Finite element analysis

A three-dimensional sample of a lower premolar tooth was created from a Micro CT scan (Skyscan Micro-CT, Kontich, Belgium) and sectioned into 1 mm-thick slices perpendicular to the longitudinal axis of the root, corresponding to the laboratory preparation level. The FEA models consisted of root dentine, sealer, and gutta-percha. The simulation model had a thickness of 1 mm, with an additional 0.01 mm layer of endodontic sealer. The FEA model was fixed at the outermost of the root dentine surface,

and the nodal force was applied only to endodontic materials.

In the FEA analysis, Young's modulus and Poisson's ratio of the sealers were determined through a three-point bending test, while the values for dentine and gutta-percha were derived from a previous study (Table 2).<sup>20</sup> The FEA results were presented in terms of the maximum shear stress area within the sample considered as a push-out test since this test is modified from the punch shear test as its more suitable test for evaluating the bond strengths of intracanal filling materials.<sup>21</sup>

**Table 2** Young's modulus and Poisson's ratio

Materials	Young's modulus (GPa)	Poisson's ratio (V)
AH Plus	0.48*	0.1*
Endosequence BC	0.44*	0.1*
MTA Fillapex	0.12*	0.1*
Dentine	18.6**	0.31**
Gutta-percha	0.074-0.079**	0.45**

\* From the laboratory, \*\*From a study of Belli et al, 2014<sup>20</sup>

### Correlation between laboratory and FEA test

The means of the micro push-out bond strength of 3 experimental sealers in 3 regions (coronal, middle and apical) were utilized to establish a comparison and determine their correlation with the FEA test results through the Pearson correlation test.

### Statistical analysis

Homogeneity and normality of data were tested by Levene's and Kolmogorov-Smirnov's tests. The outcome data of the micro push-out test were analyzed statistically by one-way analysis of variance (ANOVA). The correlation between the laboratory and FEA findings was examined using the Pearson correlation test. The level of statistical significance was set at  $\alpha=0.05$ .

## Results

### Micro push-out bond strength (Laboratory)

The mean values of micro push-out bond strength (in MPa) for each group were found in Table 3, which presented a comparison among different sealers. The laboratory tests revealed that AH Plus sealer exhibited the highest mean push-out bond strength across all three root regions. In contrast, MTA Fillapex sealer demonstrated significantly lower micro push-out bond strength than AH Plus and Endosequence BC sealers in all three root regions ( $p<0.001$ ). Nevertheless, no statistically significant difference was observed between AH Plus and Endosequence BC sealers ( $p>0.05$ ) in any of the three root regions (Table 3).

**Table 3** Micro push-out bond strength in the laboratory

Group (N=30)	Micro push-out bond strength (MPa) in laboratory test		
	Coronal (n=10) (Mean $\pm$ SD)	Middle (n=10) (Mean $\pm$ SD)	Apical (n=10) (Mean $\pm$ SD)
AH Plus	1.22 <sup>a</sup> $\pm$ 0.14	0.61 <sup>a</sup> $\pm$ 0.10	0.39 <sup>a</sup> $\pm$ 0.04
Endosequence BC	1.13 <sup>a</sup> $\pm$ 0.18	0.56 <sup>a</sup> $\pm$ 0.06	0.37 <sup>a</sup> $\pm$ 0.08
MTA Fillapex	0.50 <sup>b</sup> $\pm$ 0.08	0.19 <sup>b</sup> $\pm$ 0.06	0.16 <sup>b</sup> $\pm$ 0.06
p-value	< 0.001	< 0.001	< 0.001

Groups with different superscript letters indicate a statistically significant difference within the same column ( $p<0.001$ ).

**Micro push-out bond strength (FEA)**

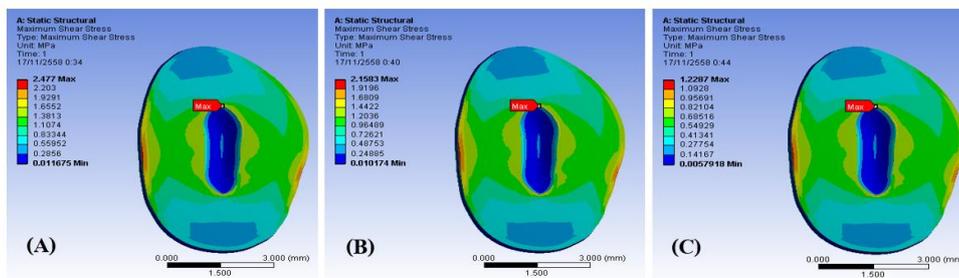
The FEA test results indicated that AH Plus exhibited the highest micro push-out bond strength (MPa) among the three root regions, while MTA Fillapex displayed the lowest bond strength, as detailed in Table 4 and Figure 2, Figure 3, and Figure 4.

**Correlation between laboratory and FEA test**

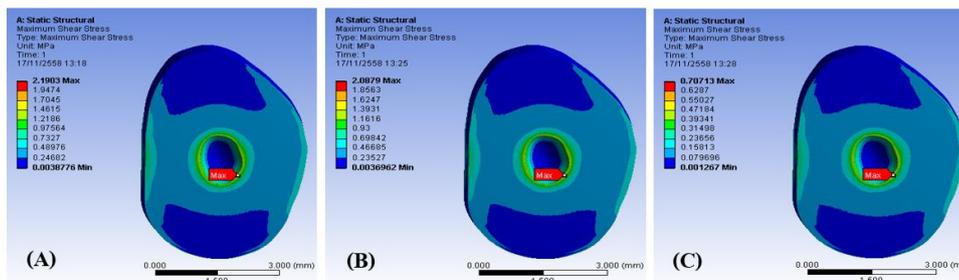
The Pearson correlation test assessed the correlation between the laboratory and the FEA test results. The findings demonstrated a highly positive relationship between both tests, with a correlation coefficient of  $r=0.869$  and a significance level of  $p<0.001$ .

**Table 4** The maximum and minimum micro push-out bond strength in the FEA.

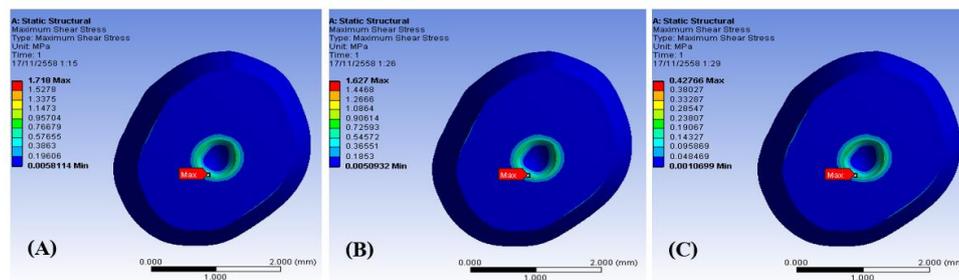
Group	Micro push-out bond strength (MPa) in FEA		
	Coronal (Maximum / Minimum)	Middle (Maximum / Minimum)	Apical (Maximum / Minimum)
AH Plus	2.48 / 0.01	2.16 / 0.01	1.23 / 0.005
Endosequence BC	2.19 / 0.003	2.09 / 0.003	0.70 / 0.001
MTA Fillapex	1.72 / 0.005	1.63 / 0.005	0.43 / 0.001



**Figure 2** The maximum and minimum shear stress (MPa) in FEA at coronal in the AH Plus (A) Endosequence BC (B) and MTA Fillapex (C).



**Figure 3** The maximum and minimum shear stress (MPa) in FEA at middle in the AH Plus (A) Endosequence BC (B) and MTA Fillapex (C).

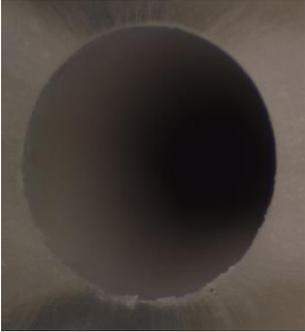
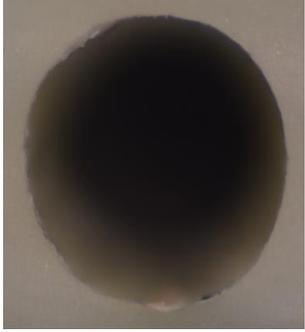
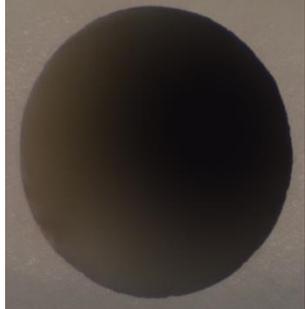


**Figure 4** The maximum and minimum shear stress (MPa) in FEA at apical in the AH Plus (A) Endosequence BC (B) and MTA Fillapex (C).

### Failure mode

A stereo microscope at 10x magnification was used to examine the failure mode of sealers. The failure mode of the AH Plus and Endosequence BC sealers showed predominantly cohesive failure (AH Plus; coronal dentine 50%, middle dentine 50% and apical dentine 70%,

Endosequence BC; coronal dentine 60%, middle dentine 60% and apical dentine 80%). In contrast, the MTA Fillapex sealer showed mostly adhesive failure (100% at coronal dentine, 80% at middle dentine and 80% at apical dentine) at the dentine-sealer interface (Figure 5).

Group	Failure		
	Adhesive failure	Cohesive failure	Mix failure
AH Plus	 Coronal 30%, Middle 40%, Apical 30%	 Coronal 50%, Middle 50%, Apical 70%	 Coronal 20%, Middle 10%, Apical 0%
Endosequence BC	 Coronal 40%, Middle 30%, Apical 20%	 Coronal 60%, Middle 60%, Apical 80%	 Coronal 0%, Middle 10%, Apical 0%
MTA Fillapex	 Coronal 100%, Middle 80%, Apical 80%	 Coronal 0%, Middle 10%, Apical 20%	 Coronal 0%, Middle 10%, Apical 0%

**Figure 5** The failure mode of sealers at 10x magnification at coronal, middle and apical sections in percentage.

## Discussion

This study compared the micro push-out bond strength of 3 kinds of root canal sealer and found a correlation between laboratory and FEA tests. According to the results obtained, the null hypothesis tests were rejected, as the one-way ANOVA and the Pearson correlation test confirmed differences in the micro push-out bond strength among three experimental sealers and a correlation between the laboratory and FEA.

The morphology of root canals varies among tooth type and location. In this study, the anatomic features of the lower premolar root canals were standardized by a proper radiographic examination performed in mesiodistal and buccolingual directions. Furthermore, we used the straight or slight curvature root to eliminate the influence of canal curvature. A large rotary file was used to complete the shaping process to create a round canal, replacing the ones with large oval canals or flattened roots. Importantly, the three different punch sizes were used according to the canal size: 0.8 mm for coronal dentine, 0.5 mm for middle dentine and 0.3 mm for apical dentine. The same punch size to the root canal wall was crucial to cover all the test material and reduce the excessive force surrounding the canal wall.

The AH Plus sealer showed the highest micro push-out bond strength at three regions of all experimental sealers. This study's result corroborates with previous reports.<sup>22-25</sup> AH Plus shows good flow and adequate setting time, allowing it to penetrate the dentinal tubules and lateral canals.<sup>23</sup> Besides, AH Plus can create a covalent bond with amino groups of collagens in root dentine. These phenomena will increase the bond strength and improve the sealing ability by mechanical interlocking.<sup>26,27</sup> Similar results were also found in previous studies, which confirmed that the push-out bond strength of the AH Plus sealer was higher than other sealers.<sup>28,29</sup> In this study, although a higher micro push-out bond strength was found in the AH Plus sealer, there was no statistical difference between the AH Plus and Endosequence BC sealer ( $p>0.05$ ). Previous study also reported no significant difference in push-out bond strength of the AH Plus and the Endosequence BC.<sup>30</sup> However, some authors

found the opposite results when they concluded that Bioceramic-based sealer presented a superior bonding force compared to AH Plus sealer. Endosequence BC can release calcium hydroxide and interact with phosphate in the dentine wall to form a hydroxyapatite layer on the canal wall and improve the bond strength.<sup>31,32</sup>

MTA Fillapex sealer showed the lowest micro push-out bond strength with a statistically significant difference from the AH Plus and Endosequence BC sealer ( $p<0.001$ ). The low bond strength can be explained by short resin tag formation in dentinal tubules and a high shrinkage rate during the setting process.<sup>24</sup> Previous studies confirmed that MTA Fillapex presented the lowest bond strength to the root canal wall.<sup>6,24,25,31,33,34</sup> A weak bonding between the MTA Fillapex and dentine wall resulted from the composition of this sealer. The salicylate resin is added to the MTA in a ratio of 1:1, which allows MTA to be used as a root canal sealer.<sup>35</sup> The high percentage of salicylate resin in MTA Fillapex is responsible for its properties, such as long setting and working times, excessive flowability, and solubility. The decrease in volume following the setting time is found in salicylate-containing root canal sealers.<sup>35,36</sup> This shrinkage will lead to the formation of short sealer tags in the dentinal tubules and increase the risk of sealer detachment from the root surface.<sup>37</sup>

The comparisons in the root sections showed the highest micro push-out bond strength at the coronal region, followed by the middle and at least in the apical part with a statically different ( $p<0.001$ ) (Table 3). The reason for this finding may be the dentinal tubules are greater and denser in the coronal region.<sup>38</sup> In the apical area, the root canal exhibits a narrower diameter, resulting in diminished smear layer removal.<sup>39</sup> Conversely, the ease of removing the smear layer, combined with larger tubule dimensions in the coronal dentine, can improve the depth and percentage of sealer penetration into the dentinal tubules when compared to the middle and apical dentine.<sup>40-42</sup> This improvement will increase the adhesion ability of the sealer to the root canal wall and prevent the dislodgement of the material filling in the root canal.

Enhancing the bonding interface between sealer and dentine wall is always the crucial goal in development process of sealer. A high bonding will reduce the risk of creating root canal gaps. In this study, AH Plus and Endosequence BC sealers showed predominantly cohesive failure. In comparison, MTA Fillapex sealer showed that the most common failure mode was adhesive failure in the dentine-sealer interface. This phenomenon could be explained by a difference in micro push-out bond strength of 3 kinds of sealer. MTA Fillapex illustrated the lowest bond strength, so bond failure was usually present in the dentine-sealer interface because the low push-out bond strength corresponded with adhesive failure and dislodgement at the dentine-sealer interface.<sup>43,44</sup> AH Plus and the Endosequence BC presented a superior bond strength to the dentine wall, therefore the bond failure usually occurred in the gutta-percha cone-sealer interface.<sup>4,28,45,46</sup>

In root canal treatment, if endodontic materials have a modulus of elasticity similar to dentine (10-20 GPa), a monoblock unit can be created in the root canal system.<sup>47</sup> The monoblock unit can prevent stress concentration at their interfaces, reinforce root and reduce tooth fracture in the masticatory and restorative procedure.<sup>48-51</sup> Gutta-percha and sealers have been accepted as the standard material in endodontics, so sealers should have the same physical properties as dentine. However, no information has been available for the modulus elasticity of the AH Plus, Endosequence BC and MTA Fillapex sealers. In this study, the three-point bending test showed that the modulus of elasticity in the AH Plus, Endosequence BC and MTA Fillapex sealers were 0.48, 0.44 and 0.12 GPa, respectively. The modulus of elasticity of experimental sealers was much lower than dentine (18.6 GPa) but relatively higher than gutta-percha (0.074-0.079 GPa).<sup>20</sup> The modulus of elasticity of root canal filling and sealer should be close to dentine to distribute stress and prevent root susceptibility to fracture.<sup>52</sup> Therefore, with a relatively low modulus of elasticity of the three sealers, these would not be able to resist fracture of root dentine. Poisson's ratio is a mechanical parameter describing

the material's elasticity property. In the laboratory, it has a value between 0.0-0.5. The model validation of three sealers showed a Poisson's ratio value of 0.1 and correlated to the brittle material.<sup>53</sup> Therefore, the monoblock concept of root canal filling to enhance fracture properties of root dentine has been questioned.<sup>54</sup>

In this study, the results of the FEA test were higher than in a laboratory. FEA was a computerized simulating program that could define a specific position, direction, and magnitude of the force with no confounding factor.<sup>55</sup> However, the relationship between the micro push-out bond strength from the laboratory and FEA with Pearson correlation had a strong positive relationship ( $r=0.869$  and  $p<0.001$ ). With the high correlation, the FEA test can possibly substitute laboratory study for evaluating new material micro push-out bond strength by adding Young's modulus and Poisson's ratio of each new material. The advantages of the FEA method not only help eliminate the limitations of laboratory tests, such as the variability of root canal samples and technique sensitivity of laboratory study, but also reduce cost and time in laboratory work. Although FEA is a useful and multifunctional technique, it has some limitations. The precise simulation of the structure of teeth remained a challenge for FEA. Furthermore, most of FEA experiments, this could assume that the distribution of forces on the canal surface is uniform.<sup>56</sup> The FEA technique is not clinically applicable compared with the conventional laboratory study.

## Conclusion

In the confines of this in-vitro study, the findings indicated that Endosequence BC exhibited a comparable micro push-out bond strength to AH Plus, surpassing MTA Fillapex sealer. Consequently, Endosequence BC emerged as a superior choice for root canal treatment. Additionally, FEA proved a valuable tool for assessing the push-out bond strength of root canal filling materials, given its strong correlation with laboratory testing.

## Clinical relevance

Endosequence BC sealer should be regarded as superior material options, particularly due to their high micro push-out bond strength to root dentine, effectively mitigating factors contributing to post-treatment failure.

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## References

1. Ørstavik D. Materials used for root canal obturation: technical, biological and clinical testing. *Endod Topic* 2005;12(1):25-38.
2. Assmann E, Scarparo RK, Böttcher DE, Grecca FS. Dentine bond strength of two mineral trioxide aggregate-based and one epoxy resin-based sealers. *J Endod* 2012;38(2):219-21.
3. Hergt A, Wiegand A, Hulsmann M, Rodig T. AH Plus root canal sealer -An updated literature review. *Quintessenz* 2015;9(4):245-65.
4. Ersahan S, Aydin C. Dislocation resistance of iRoot SP, a calcium silicate-based sealer, from radicular dentine. *J Endod* 2010;36(12):2000-02.
5. Fisher MA, Berzins DW, Bahcall JK. An *in vitro* comparison of bond strength of various obturation materials to root canal dentine using a push-out test design. *J Endod* 2007;33(7):856-58.
6. Nagas E, Uyanik MO, Eymirli A, Cehreli ZC, Vallittu PK, Lassila LVJ, et al. Dentine moisture conditions affect the adhesion of root canal sealers. *J Endod* 2012;38(2):240-44.
7. Roggendorf MJ, Ebert J, Petschelt A, Frankenberger R. Influence of moisture on the apical seal of root canal fillings with five different types of sealer. *J Endod* 2007;33(1):31-3.
8. Xuereb M, Vella P, Damidot D, Sammut CV, Camilleri J. In situ assessment of the setting of tricalcium silicate-based sealers using a dentine pressure model. *J Endod* 2015;41(1):111-24.
9. Chen WP, Chen YY, Huang SH, Lin CP. Limitations of push-out test in bond strength measurement. *J Endod* 2013;39(2):283-87.
10. Dem K, Wu Y, Kaminga AC, Dai Z, Cao X, Zhu B. The push out bond strength of polydimethylsiloxane endodontic sealers to dentine. *BMC Oral Health* 2019;19(1):181.
11. De-Deus G, Souza EM, Silva EJNL, Belladonna FG, Simões-Carvalho M, Cavalcante DM, et al. A critical analysis of research methods and experimental models to study root canal fillings. *Int Endod J* 2022; 55(Suppl 2):384-445.
12. Ahmadian L, Arbabi R, Kashani J. Compression of stress distribution in pull out and push out bond strength test set ups: a 3-D finite element stress analysis. *Int J Prosthodont* 2013;4(1):1-9.
13. Brush K. [Internet]. Finite element analysis (FEA). Available from: URL: <https://www.techtarget.com/searchsoftwarequality/definition/finite-element-analysis-FEA>.
14. Hu T, Cheng R, Shao M, Yang H, Zhang R, Gao Q, et al. Application of finite element analysis in root canal therapy. In: Moratal D, editor. *Finite Element Analysis*. London: IntechOpen; 2010. 99-120.
15. Schneider SW. A comparison of canal preparations in straight and curved root canals. *Oral Surg Oral Med Oral Pathol* 1971;32(2):271-75.
16. Khurana N, Chourasia HR, Singh G, Mansoori K, Nigam AS, Jangra B. Effect of drying protocols on the bond strength of bioceramic, MTA and Resin-based sealer obturated teeth. *Int J Clin Pediatr Dent* 2019;12(1):33-6.
17. Tedesco M, Felipe MCS, Felipe WT, Alves AMH, Bortoluzzi EA, Teixeira CS. Adhesive interface and bond strength of endodontic sealers to root canal dentine after immersion in phosphate-buffered saline. *Microsc Res Tech* 2014; 77(12):1015-22.

18. International Standard. ISO 4049/2000 Dentistry- Polymer-Based Filling, Restorative and Luting Materials. 3<sup>rd</sup> Switzerland; 2000.
  19. Balos S, Puskar T, Potran M, Milekic B, Koprivica DD, Terzija JL, et al. Modulus, strength and cytotoxicity of PMMA-silica nanocomposites. *Coatings* 2020;10(6):583.
  20. Belli S, Olcay K, Akbulut MB, Guneser MB, Eraslan O, Eskitaçcaoaylu G. Are dentine posts biomechanically intensive?: A laboratory and FEA study. *J Adhes Sci Technol* 2014;28(4):2365-77.
  21. Goracci C, Tavares AU, Fabianelli A, Monticelli F, Raffaelli O, Cardoso PC, et al. The adhesion between fiber posts and root canal walls: Comparison between microtensile and push-out bond strength measurements. *Eur J Oral Sci* 2004;112(4):353-61.
  22. Sagsen B, Ustün Y, Demirbuga S, Pala K. Push-out bond strength of two new calcium silicate-based endodontic sealers to root canal dentine. *Int Endod J* 2011;44(12):1088-91.
  23. Lee KW, Williams MC, Camps JJ, Pashley DH. Adhesion of endodontic sealers to dentine and gutta-percha. *J Endod* 2002;28(10):684-88.
  24. Baechtold MS, Mazaro AF, Crozeta BM, Leonardi DP, Tomazinho FSF, Baratto-Filho F, et al. Adhesion and formation of tags from MTA Fillapex compared with AH Plus<sup>®</sup> cement. *RSBO [Internet]* 2014;11(1):71-6. Available from: [http://revodonto.bvsalud.org/scielo.php?script=sci\\_arttext&pid=S1984-56852014000100011](http://revodonto.bvsalud.org/scielo.php?script=sci_arttext&pid=S1984-56852014000100011)
  25. Gurgel-Filho ED, Leite FM, Lima JB, Montenegro JPC, Saavedra F, Silva EJNL. Comparative evaluation of push-out bond strength of a MTA-based root canal sealer. *Braz J Oral Sci* 2014;13(2):114-17.
  26. Mamootil K, Messer HH. Penetration of dentinal tubules by endodontic sealer cements in extracted teeth and *in vivo*. *Int Endod J* 2007;40(11):873-81.
  27. Weis MV, Parashos P, Messer HH. Effect of obturation technique on sealer cement thickness and dentinal tubule penetration. *Int Endod J* 2004;37(10):653-63.
  28. Donnermeyer D, Dornseifer P, Schäfer E, Dammeschke T. The push-out bond strength of calcium silicate-based endodontic sealers. *Head Face Med* 2018;14(1):13.
  29. Yap WY, CheAb AZA, Azami NH, Al-Haddad AY, Khan AA. An *in vitro* comparison of bond strength of different sealers/obturation systems to root dentine using the push-out test at 2 weeks and 3 months after obturation. *Med Princ Pract* 2017;26(5):464-69.
  30. Shokouhinejad N, Gorjestani H, Nasseh AA, Hoseini A, Mohammadi M, Shamshiri AR. Push-out bond strength of gutta-percha with a new bioceramic sealer in the presence or absence of smear layer. *Aust Endod J* 2011;39(3):102-06.
  31. Delong C, He J, Woodmansey KF. The effect of obturation technique on the push-out bond strength of calcium silicate sealers. *J Endod* 2015;41(3):385-88.
  32. Al-Hiyasat AS, Alfirjani SA. The effect of obturation techniques on the push-out bond strength of a premixed bioceramic root canal sealer. *J Dent [Internet]* 2019;89:103169. Available from: <https://pubmed.ncbi.nlm.nih.gov/31326527/>
  33. Madhuri GV, Varri S, Bolla N, Mandava P, Akkala LS, Shaik J. Comparison of bond strength of different endodontic sealers to root dentine: An *in vitro* push-out test. *J Conserv Dent* 2016;19(5):461-64.
  34. Abada HM, Farag AM, Alhadainy HA, Darrag AM. Push-out bond strength of different root canal obturation systems to root canal dentine. *Tanta Dental Journal* 2015;12(3):185-91.
  35. Vitti RP, Prati C, Sinhoreti MAC, Zanchi CH, Souza ESMG, Ogliari FA, et al. Chemical-physical properties of experimental root canal sealers based on butyl ethylene glycol disalicylate and MTA. *Dent Mater* 2013;29(12):1287-94.
  36. Prado MC, Carvalho NK, Vitti RP, Ogliari FA, Sassone LM, Silva EJNL. Bond strength of experimental root canal sealers based on MTA and butyl ethylene glycol disalicylate. *Braz Dent J* 2018;29(2):195-201.
  37. Amoroso-Silva PA, Guimarães BM, Marciano MA, Duarte MAH, Cavenago BC, Ordinola-Zapata R, et al. Microscopic analysis of the quality of obturation and physical properties of MTA Fillapex. *Microsc Res Tech* 2014;77(12):1031-36.
-

38. Kuci A, Alacam T, Yavas O, Ergul-Ulger Z, Kayaoglu G. Sealer penetration into dentinal tubules in the presence or absence of smear layer: A confocal laser scanning microscopic study. *J Endod* 2014;40(10):1627-31.
39. Chandra SS, Shankar P, Indira R. Depth of penetration of four resin sealers into radicular dentinal tubules: A confocal microscopic study. *J Endod* 2012;38(10):1412-16.
40. Piai GG, Duarte MAH, Nascimento AL, Rosa RA, Marcus-Vinicius RS, Vivan RR. Penetrability of a new endodontic sealer: A confocal laser scanning microscopy evaluation. *Microsc Res Tech* 2018;81(11):1246-49.
41. Ortiz-Blanco B, Sanz JL, Llena C, Lozano A, Forner L. Dentine sealing of calcium silicate-based sealers in root canal retreatment: A confocal laser microscopy study. *J Funct Biomater* 2022;13(3):114.
42. Lemos AF, Vertuan GS, Weissheimer T, Michel CHT, Só GB, Rosa RA, et al. Evaluation of the dentinal tubule penetration of an endodontic bioceramic sealer after three final irrigation protocols. *J Res Dent* 2022;10(1): 14-9.
43. Sonmez IS, Sonmer D, Almaz ME. In vitro evaluation of apical microleakage of a new MTA-based sealer. *Eur Arch Paediatr Dent* 2012;13(5):252-55.
44. Orhan EO, Irmak Ö, Mumcu E. Evaluation of the bond strengths of two novel bioceramic cement using a modified thin-slice push-out test model. *Int J Appl Ceram Technol* 2019;16(5):1998-2005.
45. Jainaen A, Palamara JEA, Messer HH. Push-out bond strengths of the dentine-sealer interface with and without a main cone. *Int Endod J* 2007;40(11):882-90.
46. Gade VJ, Dilip Belsare L, Patil S, Bhede R, Gade JR. Evaluation of push-out bond strength of endosequence BC sealer with lateral condensation and thermoplasticized technique: An *in vitro* study. *J Conserv Dent* 2015;18(2):124-27.
47. Kinney JH, Balooch M, Marshall GW, Marshall SJ. A micromechanics model of the elastic properties of human dentine. *Arch Oral Biol* 1999; 44(1):813-22.
48. Sidoli GE, King PA, Setchell DI. An *in vitro* evaluation of a carbon fiber-based post and core system. *J Prosthet Dent* 1997;78(1):5-9.
49. Cheung W. A review of the management of endodontically treated teeth: Post, core and the final restoration. *J Am Dent Assoc* 2005;136(5):611-19.
50. Dalat DM, Spangberg LSW. Effect of post preparation on the apical seal of teeth obturated with plastic thermafil obturators. *Oral Surg Oral Med Oral Pathol* 1993;76(6):760-65.
51. Saunders EM, Saunders WP, Rashid MYA. The effect of post space preparation on the apical seal of root fillings using chemically adhesive materials. *Int Endod J* 1991;24(2):51-7.
52. Sidoli GE, King PA, Setchell DI. An *in vitro* evaluation of a carbon fiber-based post and core system. *J Prosthet Dent* 1997;78(1):5-9.
53. Mott PH, Roland CM. Limits to Poisson's ratio in isotropic materials-general result for arbitrary deformation. *Physica Scripta* 2013;87(5):055404.
54. Jainaen A, Palamara JEA, Messer HH. The effect of resin-based sealers on fracture properties of dentine. *Int Endod J* 2009;42(2):136-43.
55. Soares JC, Versluis A, Valdivia ADCM, Bicalho AA, Verissimo C, Barreto BCF, et al. Finite element Analysis in Dentistry - Improving the quality of oral health care. In: Moratal D, editor. *Finite Element Analysis - From Biomedical Applications to Industrial Developments*. London: InTechOpen; 2012. 25-56.
56. Uzunoglu-Özyürek E, Küçükaya-Eren S, Eraslan O, Belli S. Critical evaluation of fracture strength testing for endodontically treated teeth: A finite element analysis study. *Restor Dent Endod* 2019;44(2): e15

### Corresponding Author

*Angsana Jainaen*

*Department of Restorative Dentistry,*

*Faculty of Dentistry, Khon Kaen University*

*Amphur Muang, Khon Kaen, 40002.*

*Tel. : +66 43 202 405 #45143*

*Fax : +66 43 202 862*

*E-mail : angjai@kku.ac.th*

# การเปรียบเทียบค่าความแข็งแรงกดออกกระดับ จุลภาคของซีลเลอร์ชนิดเอเอชพลัส เอ็นโดซีควนซ์บีซี และเอ็มทีเอฟอีพีลเอเพ็กในห้องปฏิบัติการและการ วิเคราะห์ด้วยระเบียบวิธีไฟไนต์เอลิเมนต์

ประภัสสรา ทันอินทรอาจ\* Nguyen Thanh Quang\*\* ณัฐชิววัฒน์ พลดี\*\*\* อังสนา ใจแน่น\*\*\*\*

## บทคัดย่อ

วัตถุประสงค์ของการศึกษาเพื่อประเมินผลค่าความแข็งแรงกดออกกระดับจุลภาคทางห้องปฏิบัติการระหว่างซีลเลอร์ 3 ชนิด ได้แก่ เอเอชพลัส เอ็นโดซีควนซ์บีซี และเอ็มทีเอฟอีพีลเอเพ็ก และสร้างแบบจำลองระเบียบวิธีไฟไนต์เอลิเมนต์ เพื่อประเมินความสัมพันธ์ของค่าความแข็งแรงกดออกกระดับจุลภาคทางห้องปฏิบัติการ โดยใช้ฟันกรามน้อยล่างรากเดียว 30 ซี่ เตรียมคลองรากฟันและอุดด้วยแมททาคาเพอร์ชา โคนร่วมกับวิธีออร์มเวอร์คิคอลคอมแพคชัน แบ่งเป็น 3 กลุ่ม กลุ่มละ 10 ซี่ อุดด้วยซีลเลอร์ 3 ชนิด ได้แก่ เอเอชพลัส เอ็นโดซีควนซ์บีซี และเอ็มทีเอฟอีพีลเอเพ็ก หลังจากเก็บตัวอย่างไว้ในตู้อบ 37°C และความชื้นสัมพัทธ์ 100% เป็นเวลา 2 สัปดาห์ เตรียมชิ้นตัวอย่างให้มีความหนา  $1 \pm 0.1$  มม. ใน 3 ตำแหน่งคือ คอฟัน กึ่งกลางรากฟันและบริเวณปลายรากฟัน นำไปทดสอบค่าความแข็งแรงกดออกกระดับจุลภาคและตรวจสอบการแตกหักที่ก่าลึงขย 10 เท่า สร้างตัวอย่างขนาด  $2 \times 2 \times 2.5$  มม. 3 ตัวอย่างต่อซีลเลอร์ เพื่อหาค่าโมดูลัสความยืดหยุ่นและวิเคราะห์ระเบียบวิธีไฟไนต์เอลิเมนต์ด้วย ANSYS workbench เปรียบเทียบค่าความแข็งแรงกดออกกระดับจุลภาคด้วย one-way ANOVA และหาค่าสัมประสิทธิ์ความสัมพันธ์แบบเพียร์สันของความแข็งแรงกดออกกระดับจุลภาคทางห้องปฏิบัติการและจากการวิเคราะห์ด้วยระเบียบวิธีไฟไนต์เอลิเมนต์ที่  $p < 0.05$  ผลการทดลองทางห้องปฏิบัติการพบว่า เอเอชพลัสและเอ็นโดซีควนซ์บีซีมีค่าเฉลี่ยความแข็งแรงกดออกกระดับจุลภาค สูงกว่า เอ็มทีเอฟอีพีลเอเพ็กอย่างมีนัยสำคัญทางสถิติจาก ( $p < 0.001$ ) แต่ไม่พบความแตกต่างอย่างมีนัยสำคัญทางสถิติระหว่างเอเอชพลัสและเอ็นโดซีควนซ์บีซี ( $p > 0.05$ ) การวิเคราะห์ด้วยระเบียบวิธีไฟไนต์เอลิเมนต์พบค่าความแข็งแรงกดออกกระดับจุลภาคในบริเวณตัวฟันในเอเอชพลัสสูงที่สุด รองลงมาคือเอ็นโดซีควนซ์บีซีและเอ็มทีเอฟอีพีลเอเพ็ก (2.48, 2.16 และ 1.23 เมกะปาสคาล ตามลำดับ) บริเวณกึ่งกลางรากฟันมีค่าเท่ากับ 2.19, 2.09 และ 0.70 เมกะปาสคาล และบริเวณปลายรากฟันมีค่าเท่ากับ 1.72, 1.63 และ 0.43 เมกะปาสคาล ตามลำดับ ค่าเฉลี่ยความแข็งแรงกดออกกระดับจุลภาคทางห้องปฏิบัติการและจากการวิเคราะห์ด้วยระเบียบวิธีไฟไนต์เอลิเมนต์มีความสัมพันธ์เชิงบวกค่อนข้างสูง ( $r = 0.869$ ) จากการทดลองนี้สรุปได้ว่า เอ็นโดซีควนซ์บีซีมีค่าเฉลี่ยความแข็งแรงกดออกกระดับจุลภาคใกล้เคียงกับเอเอชพลัสและสูงกว่าเอ็มทีเอฟอีพีลเอเพ็ก พบความสัมพันธ์เชิงบวกค่อนข้างสูงของค่าเฉลี่ยความแข็งแรงกดออกกระดับจุลภาคระหว่างการทดลองทางห้องปฏิบัติการและจากการวิเคราะห์ระเบียบวิธีไฟไนต์เอลิเมนต์

คำิขรห้ส: แคลเซียมซิลิเกตซีลเลอร์/ อีพ็อกซีเรซินเบสซีลเลอร์/ ระเบียบวิธีไฟไนต์เอลิเมนต์/ ค่าความแข็งแรงกดออกกระดับจุลภาค/ ซีลเลอร์ในงานรักษากล่องรากฟัน

## ผู้รับผิดชอบบทความ

อังสนา ใจแน่น

สาขาวิชาทันตกรรมบูรณะ

คณะทันตแพทยศาสตร์ มหาวิทยาลัยขอนแก่น

อำเภอเมือง จังหวัดขอนแก่น 40002

โทรศัพท์ : 043 202 405 # 45143

โทรสาร : 043 202 862

จดหมายอิเล็กทรอนิกส์ : angjai@kku.ac.th

\*แผนกทันตกรรม โรงพยาบาลแก่งคอย อำเภอแก่งคอย จังหวัดสระบุรี

\*\* คณะทันตแพทยศาสตร์ มหาวิทยาลัยตราวิงห์ ประเทศเวียดนาม

\*\*\* ภาควิชาเครื่องมือกล ศูนย์วิจัยและพัฒนา โครงสร้างมูลฐานอย่างยั่งยืน คณะวิศวกรรมศาสตร์ มหาวิทยาลัยขอนแก่น อำเภอเมือง จังหวัดขอนแก่น

\*\*\*\* สาขาวิชาทันตกรรมบูรณะ คณะทันตแพทยศาสตร์ มหาวิทยาลัยขอนแก่น อำเภอเมือง จังหวัดขอนแก่น