Original Article

pISSN, eISSN 0125-5614
M Dent J 2024; 44 (2) : 55-66

pH changes of root dentin following root canal filling with three different calcium silicate-based cements over 4-week period

Kessara Kaewkiew[1], Chitpol Chaimanakarn[2]

[1] *Residency Training Program in Endodontics, Department of Operative Dentistry and Endodontics, Faculty of Dentistry, Mahidol University, Bangkok, Thailand*
[2] *Department of Operative Dentistry and Endodontics, Faculty of Dentistry, Mahidol University, Bangkok, Thailand*

Objective: To evaluate the pH changes in root dentin after root canals were filled with ProRoot MTA, Bio-MA or Biodentine at different root levels and times.

Materials and Methods: Fifty-three extracted single-rooted mandibular premolars were instrumented, and three different locations of cavities were prepared on the root surface-two at the middle and one at the apical root levels. Three experimental groups (n=16) were filled with ProRoot MTA, Bio-MA or Biodentine, while a control group (n=5) was filled with deionized water. pH measurements were taken at 2 hours, 1 day, 1-4 weeks. Analysis was performed using the three-way mixed ANOVA ($p< 0.05$).

Results: Significant alkaline pH changes occurred over a 4-week period in experimental groups at all root levels ($p < .001$). The Bio-MA group exhibited the highest pH value (9.18) at 1 week at the apical root level and 1 day at the inner middle root levels. The highest pH values for ProRoot MTA and Biodentine groups were 9.12 and 9.07 at 2 weeks and 2 hours at the inner middle and apical root levels, respectively. Notably, the pH values at the outer middle root level were the lowest.

Conclusions: Alkaline pH changes in root dentin persisted for 4 weeks, with the highest recorded values ranging from 9.07-9.18. The outer middle root level displayed the lowest pH values.

Keywords: calcium silicate-based cements, hydroxyl ion diffusion, pH changes, root canal filling, root dentin pH

How to cite: Kaewkiew K, Chaimanakarn C. pH changes of root dentin following root canal filling with three different calcium silicate-based cements over 4-week period. M Dent J 2024;44(2): 55-66.

Introduction

Nonsurgical root canal treatment has been purposed to prevent and treat apical periodontitis [1] by eliminating microorganisms from the infected root canal system, and the prevention of recontamination. However, recent studies of endodontic chemomechanical instrumentation reveal that it may not consistently eradicate all microorganisms and provide the sterility of the root canal [2]. Consequently, root canal obturation play a crucial role in preventing reinfection by entombing residual bacteria. It might be beneficial for the root canal filling to have some remaining antibacterial effect after obturation [3]. The standard for root canal filling is a combination of core material and sealer [4]. Recently, calcium silicate-based cement such as Mineral Trioxide Aggregate (MTA) has been recommended as a root canal filling material due to its specific characteristics which conform to the requirement of filling material such as its sealing ability, biocompatibility, and antibacterial activity [6]. Therefore, given these characteristics, it can be used as root-end filling material,

Corresponding author: Chitpol Chaimanakarn
Department of Operative Dentistry and Endodontics, Faculty of Dentistry, Mahidol University,
6 Yothi Road, Ratchathewi, Bangkok 10400, Thailand
Tel: +662 200 7825, Fax: +662 200 7824
E-mail: chitpol.cha@mahidol.ac.th, chitkarn@hotmail.com
Received: 8 April 2024 Revised: 24 June 2024 Accepted: 26 June 2024

perforation repair material, root resorption filling material, or as typical root canal filling material that requires no sealer to obturate [7, 8].

The main advantages of calcium silicate-based cement come from its unique setting reactions, which release calcium and hydroxyl ions. These ion products contribute to its bioactive properties [9]. Hydroxyl ions also cause localized high alkaline conditions, which play an important role in the antimicrobial effect [10-12]. Several studies have also confirmed hydroxyl ion diffusion through dentin. This was accomplished by detecting the pH changes of root dentin (high alkaline level) after using the calcium hydroxide medication [11-14]. For calcium silicate-based cement, previous studies have shown pH changes on the external simulated root surface occurred in resorption defects over time subsequent to intracanal MTA placement [15]. However, only one calcium silicate-based cement was used in these studies. Additionally, the studies did not evaluate the hydroxyl ion diffusion dynamic of the different depths and levels of the root dentin. The different diameters and densities of the dentinal tubule vary along the depth and level of the root, so it may affect the diffusion of hydroxyl ion. Another study compared pH changes at different root levels of two materials, White MTA, the first calcium silicate-based cement developed, and EndoSequence Root Repair Material, which has improved handling property [16]. They reported that root level and time are factors that cause differences in pH changes of root dentin in both intracanal materials. However, the depth of root dentin is also important in evaluating hydroxyl ion diffusion ability through root dentin due to the difference in dentin permeability [17].

Calcium silicate-based cement is being continuously developed. For example, Biodentine has been modified to improve handling characteristics and setting time [18]. Furthermore, in Thailand, Thai white Portland cement (TWPC), commercially available as Bio-MA, has been developed and compared to White MTA, both materials are comparable in many aspects of physical properties [19]. These developments were made by the addition of different compositions to reduce the drawbacks of the original MTA.

Therefore, this study aims to evaluate pH changes of root dentin at apical and middle root levels with different depths of root dentin over 4-week period after the root canal has been filled with ProRoot White MTA and other calcium silicate-based cements including Bio-MA and Biodentine.

Materials and methods

1. Specimen preparation

Fifty-three extracted single-rooted mandibular premolars without cracks, root caries, or root resorption were used in this study. An access opening to the pulp chamber was performed, and a No. 15 K-file was used to confirm root canal patency and establish the working length by subtracting 0.5 mm from the apical foramen. All specimens underwent instrumentation using ProTaper Next® Ni-Ti rotary instruments (Dentsply Sirona, Ballaigues, Switzerland) from X1 (size 17/.04) to X4 (size 40/.06). Each set of files was replaced after every four teeth. Between each file, the root canal was irrigated with 1 ml of 2.5% NaOCl, using a 27-gauge needle. The final irrigation was done with 3 ml of 17% EDTA for 1 minute, followed by 5 ml of 2.5% NaOCl, and finished with 5 ml of distilled water. Subsequently, the root canal was dried with paper points. Periapical digital radiographs of the prepared specimens were taken (proximal view) for measurement of buccal and lingual root dentin thickness.

Three cavities, each approximately 1.5 mm in diameter and 1.5 mm in depth were prepared using a cutting-edge high-speed cylindrical diamond bur (Intensiv SA, Montagnola, Switzerland) at two levels on each prepared tooth. At the middle level (8 mm from the apex), the cavities were drilled at two different depths. A buccal cavity was cut perpendicularly to the root canal wall at a distance of 0.5 mm from the inner middle root canal wall (inner middle root level). A lingual cavity was cut to a distance of 1 mm from the outer middle root canal wall (outer middle root level). At the apical level (4 mm from the apex), a lingual cavity was perpendicularly cut to a distance of 0.5 mm from the root canal wall. Subsequently, a periapical digital radiograph was taken again to confirm the position, depth, and remaining dentin thickness of the cavities. All cavities for each specimen were irrigated with 17% EDTA (3ml for 1 minute), followed by 5 ml of distilled water to remove the smear layer. Throughout the experimental periods, specimens were stored in vials containing deionized water at 100% humidity and 37°C.

2. Placement of root canal filling material

The specimens were divided into three experimental groups, each comprising 16 specimens, and a negative control group with 5 specimens. In each experimental group, the root canal was filled with a different calcium silicate-based cement: Group 1 was filled with ProRoot White MTA (Dentsply, Tulsa, OK, USA), Group 2 was filled with Bio-MA (M-Dent/SCG, Bangkok, Thailand), and Group 3 was filled with Biodentine (Septodent, Saint-maar-des-fosses, France).

For the experimental groups, each material was delivered into the root canal using an MTA carrier (MAP System, Dentsply Tulsa Dental, OK, USA) and compacted with endodontic pluggers and paper points to a level 10 mm from the apex. In the negative control group, distilled water was filled into the root canal. Subsequently, a 4 mm-thick layer of temporary filling material (Caviton, GC Corporation, Tokyo, Japan) was used to seal the access. The specimens were then allowed to set fully for 5 hours. After the placement of root canal filling material, the specimens were restored in vials at 100% humidity and 37°C until each test period.

3. Determination of pH

Each tooth was removed from a container, rinsed with deionized water, and then blot-dried within the dentin cavities using a paper point. Approximately 2 µl of deionized water was dropped into the dentin cavity and left for 5 minutes. Subsequently, the tip of pH microelectrode (MI-413E, Microelectrodes, Inc., USA) was submerged to measure the pH of the deionized water in the dentin cavity and remained in the cavity until the pH value stabilized. This pH measurement process was repeated three times for each sample. Afterward, the tooth was returned to its container. All procedures were conducted at the specific time intervals in this study: 2 hours, 1 day, 1 week, 2 weeks, 3 weeks, and 4 weeks.

4. Statistical analysis

The average pH value from each sample was used for statistical analysis. The statistical analysis was calculated using SPSS for Windows version 18.0 (SPSS INC, Chicago). Normal distribution of the data was assessed with the Kolmogorov-Smirnov test, and the homogeneity of variances was examined using Levene's test. To analyze the difference in pH values among different materials, time points, and areas of root dentin, a three-way mixed ANOVA was employed. Statistical significance was set at a P-value less than 0.05.

5. Ethical Approval

All procedures performed in this study were in accordance with the principles of the Declaration of Helsinki. This research was approved by the Ethics Committee of the Faculty of Dentistry and the Faculty of Pharmacy, Mahidol University Institutional Review Board (certificate of exemption no. MU-DT/PY-IRB 2019/048.2608).

Results

After tooth preparation, the remaining dentin thickness between the test cavity and root canal was properly controlled. At the apical root level, it was 0.59 ± 0.14 mm; at the inner middle root level, it was 0.55 ± 0.13 mm; and at the outer middle root level, it was 1.13 ± 0.21 mm.

The mean pH values of the negative control group ranged from 7.55 to 7.90 throughout the study period. The mean pH values and standard deviations of each calcium silicate-based cement group at different root levels and time points are shown in Table 1 and Table 2. The Bio-MA group exhibited the highest pH values (9.18) at both apical and inner middle root levels after 1 week and 1 day. The highest pH values of the ProRoot MTA and Biodentine groups were 9.12 and 9.07, observed at 2 weeks and 2 hours, respectively, at the inner middle and apical root levels.

Table 1 Mean ± SD of pH values of each calcium silicate-based cement group at three root levels over 4-week period.

		Time						
Root level	Material	initial	2 h	1 d	1 wk.	2 wk.	3 wk.	4 wk.
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD
Apical	ProRoot MTA	7.70 ± 0.33	8.41 ± 0.38^{a}	9.07 ± 0.27	9.10 ± 0.36^{a}	8.97 ± 0.34^{a,b}	8.87 ± 0.34^{a,b}	8.80 ± 0.22^{a}
	Bio-MA	7.79 ± 0.28	8.31 ± 0.29^{a}	9.14 ± 0.36	9.18 ± 0.34^{a}	9.15 ± 0.33^{a}	9.09 ± 0.33^{a}	8.88 ± 0.36^{a}
	Biodentine	7.83 ± 0.29	9.07 ± 0.81^{b}	9.00 ± 0.34	8.71 ± 0.32^{b}	8.68 ± 0.33^{b}	8.60 ± 0.28^{b}	8.53 ± 0.23^{b}
	*P-value	0.481	0.000	0.467	0.01	0.001	0.000	0.003
Inner middle	ProRoot MTA	7.81 ± 0.24	8.56 ± 0.52	9.08 ± 0.37^{a,b}	9.03 ± 0.41^{a}	9.12 ± 0.34^{a}	9.03 ± 0.21^{a}	8.91 ± 0.26^{a}
	Bio-MA	7.75 ± 0.21	8.33 ± 0.47	9.18 ± 0.40^{a}	9.04 ± 0.42^{a}	9.13 ± 0.32^{a}	9.07 ± 0.33^{a}	9.08 ± 0.32^{a}
	Biodentine	7.81 ± 0.22	8.77 ± 0.62	8.73 ± 0.45^{b}	8.70 ± 0.23^{b}	8.74 ± 0.31^{b}	8.65 ± 0.27^{b}	8.61 ± 0.24^{b}
	*P-value	0.720	0.076	0.008	0.016	0.001	0.000	0.000
Outer middle	ProRoot MTA	7.71 ± 0.29	8.32 ± 0.46	8.55 ± 0.43^{a,b}	8.67 ± 0.36^{a,b}	8.79 ± 0.32^{a,b}	8.86 ± 0.29^{a}	8.76 ± 0.24^{a}
	Bio-MA	7.78 ± 0.26	8.13 ± 0.30	8.78 ± 0.40^{a}	8.92 ± 0.40^{a}	8.87 ± 0.25^{a}	8.82 ± 0.27^{a}	8.71 ± 0.25^{a}
	Biodentine	7.65 ± 0.35	8.54 ± 0.68	8.40 ± 0.36^{b}	8.47 ± 0.24^{b}	8.58 ± 0.21^{b}	8.51 ± 0.25^{b}	8.48 ± 0.28^{b}
	*P-value	0.448	0.084	0.036	0.002	0.010	0.000	0.007

The mean difference is significant at $p < .05$

(, Three-way mixed ANOVA for comparing mean root dentin pH values of different types of calcium silicate-based cement in the same test period and root level)*

(^{a}, ^{b} indicates the statistical significance between calcium silicate-based cements at each time point. Different letters denote significant differences, while the same letter indicates no significant difference.)

Table 2 Mean ± SD of pH values at each root level of three calcium silicate-based cement groups over 4-week period.

Material	Root level	Time							†P-value
		initial	2 h	1 d	1 wk.	2 wk.	3 wk.	4 wk.	
		Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	Mean ± SD	
ProRoot MTA	Apical	7.70 ± 0.33	8.41 ± 0.38	9.07 ± 0.27[a]	9.10 ± 0.36[a]	8.97 ± 0.34[a]	8.87 ± 0.34[a]	8.80 ± 0.22	0.000
	Inner middle	7.81 ± 0.24	8.56 ± 0.52	9.08 ± 0.37[a]	9.03 ± 0.41[a]	9.12 ± 0.34[a]	9.03 ± 0.21[b]	8.91 ± 0.26	0.000
	Outer middle	7.71 ± 0.29	8.32 ± 0.46	8.55 ± 0.43[b]	8.67 ± 0.36[b]	8.79 ± 0.32[b]	8.86 ± 0.29[a]	8.76 ± 0.24	0.000
	*P-value	0.102	0.309	0.000	0.000	0.001	0.010	0.118	
Bio-MA	Apical	7.79 ± 0.28	8.31 ± 0.29	9.14 ± 0.36[a]	9.18 ± 0.34[a]	9.15 ± 0.33[a]	9.09 ± 0.33[a]	8.88 ± 0.36[a]	0.000
	Inner middle	7.75 ± 0.21	8.33 ± 0.47	9.18 ± 0.40[a]	9.04 ± 0.42[a]	9.13 ± 0.32[a]	9.07 ± 0.33[a]	9.08 ± 0.32[b]	0.000
	Outer middle	7.78 ± 0.26	8.13 ± 0.30	8.78 ± 0.40[b]	8.92 ± 0.40[b]	8.87 ± 0.25[b]	8.82 ± 0.27[b]	8.71 ± 0.25[a]	0.000
	*P–value	0.740	0.453	0.000	0.021	0.001	0.000	0.000	
Biodentine	Apical	7.83 ± 0.29[a]	9.07 ± 0.81[a]	9.00 ± 0.34[a]	8.71 ± 0.32[a]	8.68 ± 0.33	8.60 ± 0.28	8.53 ± 0.23	0.000
	Inner middle	7.81 ± 0.22[a,b]	8.77 ± 0.62[a]	8.73 ± 0.45[a]	8.70 ± 0.23[a]	8.74 ± 0.31	8.65 ± 0.27	8.61 ± 0.24	0.000
	Outer middle	7.65 ± 0.35[b]	8.54 ± 0.68[b]	8.40 ± 0.36[b]	8.47 ± 0.24[b]	8.58 ± 0.21	8.51 ± 0.25	8.48 ± 0.28	0.000
	*P–value	0.006	0.014	0.000	0.004	0.127	0.108	0.217	

The mean difference is significant at p < .05.

*(Three-way mixed ANOVA for *, Comparing mean root dentin pH values of different root level in the same type of calcium silicate-based cement and test period; †, Comparing mean root dentin pH values of different test periods in the same type of calcium silicate-based cement and root level)*

([a], [b] indicates the statistical significance. Different letters denote significant differences between root levels at each time point, while the same letter indicates no significant difference.)

From the results of the three-way mixed ANOVA, there are statistically significant main effects of material type ($p = 0.005$), root level ($p < 0.001$), and time point ($p < 0.001$) on the pH values. For the interaction effect between two factors, there are statistically significant interactions between material and time point and between root level and time point ($p < 0.001$). There is also a statistically significant three-way interaction among material, root level, and time point ($p = 0.044$).

Time points

Significant pH changes occurred over time within each calcium silicate-based cement group ($p < .001$) (Table 2). ProRoot MTA and Bio-MA groups exhibited a similar pattern of pH changes. A significant increase in the pH values was observed in the first 2 hours, reaching the highest pH values primarily at 1 day. Subsequently, the pH values remained constant until the 4-week time interval. The highest pH values of the ProRoot MTA group were detected at 1 week (pH 9.10) at the apical root level, 2 weeks (pH 9.12) at the inner middle root level, and 3 weeks (pH 8.86) at the outer middle root level (Figure 2A). In the Bio-MA group, the highest pH values were observed at 1 day (pH 9.18) at the inner middle root level, 1 week at the apical level (pH 9.18), and 1 week at the outer middle root level (pH 8.92) (Figure 2B). In the Biodentine group (Figure 2C), the pH values increased significantly, reaching the highest values at 2 hours at the apical (pH 9.07) and inner middle (pH 8.77) root levels. However, at the outer middle root level, the highest pH value of 8.58 was observed at 2 weeks. Afterward, the pH values remained constant until the end of the study period.

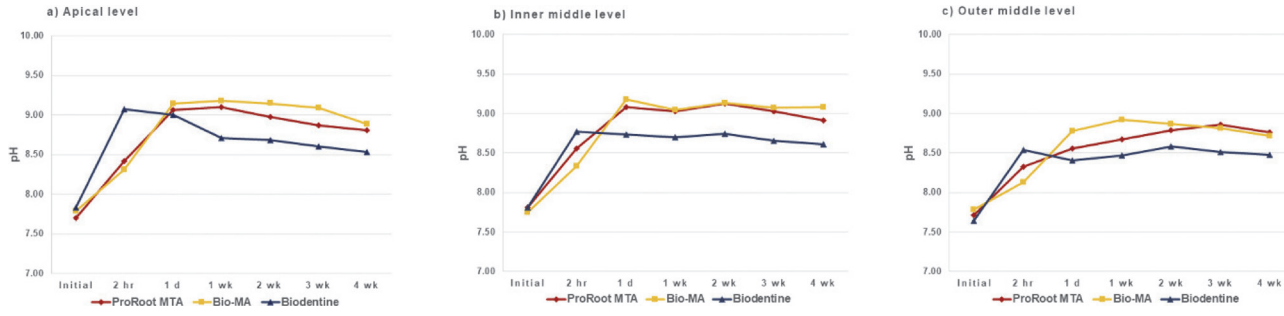


Figure 1 pH changes of root dentin after root canal filling with different calcium silicate-based cements at (a) the apical, (b) the inner middle, and (c) the outer middle root levels over 4-week period

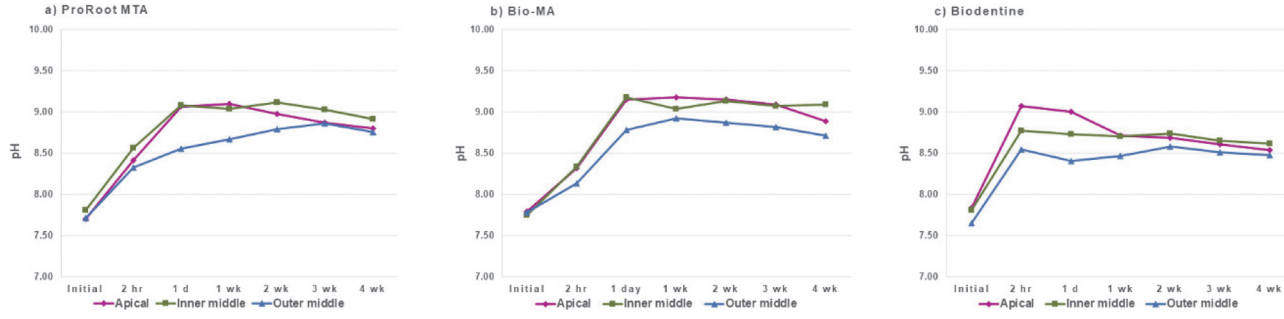


Figure 2 pH changes of root dentin after root canal filling with (a) ProRoot MTA, (b) Bio-MA, and (c) Biodentine at each root level over 4-week period.

Calcium silicate-based cements

At 2 hours, the Biodentine group exhibited the highest pH values, followed by the ProRoot MTA and Bio-MA groups, respectively, at all root levels (Table 1). There were no significant differences in pH values between the ProRoot MTA, Biodentine, and Bio-MA groups, except at the apical root level. The Biodentine group showed higher pH values than both the ProRoot MTA and Bio-MA groups ($p < .001$) (Figure 1).

At 1 day, 1 week, and 2 weeks, the Bio-MA group exhibited the highest pH values, followed by the ProRoot MTA and Biodentine groups, respectively, at all root levels. Although the pH values of Bio-MA group were higher than those of the ProRoot MTA group across all root levels, these differences were not statistically significant. Notably, at the middle root level, the pH values of Bio-MA group were significantly higher than Biodentine group. Furthermore, the pH values of the ProRoot MTA group were significantly higher than those of the Biodentine group at 1 week for the apical and inner middle root levels and at 2 weeks for the inner middle root level.

At 3 weeks and 4 weeks, the Bio-MA group exhibited the highest pH values at the apical and inner middle root levels, while ProRoot MTA had the highest pH value at the outer middle root level. However, there were no significant differences observed at any root levels. Biodentine consistently showed the lowest pH values. The pH values of the Bio-MA group were significantly higher than those of the Biodentine group

at all root levels, and ProRoot MTA exhibited significantly higher pH values than the Biodentine group at all root levels except the apical root level at 3 weeks.

Root levels

In each calcium silicate-based cement group, the pH values at the outer middle root level were consistently the lowest at each time interval. Conversely, the pH values at the inner middle and apical root levels did not exhibit significant differences at each time interval. In both the ProRoot MTA and Bio-MA groups, the pH values at the outer middle root level were significantly lower than those at both the inner middle and apical root levels at 1 day, 1 week and 2 weeks. In the Biodentine group, the pH values at the outer middle root level were significantly lower than those at both the inner middle and apical root levels at 2 hours, 1 day, and 1 week.

Discussion

One of the physical properties of calcium silicate-based cement is its high alkaline pH [9, 20]. Several studies have assessed the pH changes of root dentin following root canal filling with calcium silicate-based cement. These studies employed experimental methodologies designed to investigate the diffusion of hydroxyl ions through root dentin [15, 16, 21]. Two measurement techniques were utilized: first, immersion media measurement, where pH was assessed in the media surrounding the samples, and second, direct measurement at the root surface. To represent the objectives of this study, the pH values of root dentin filled with calcium silicate-based cements in the drilled cavities on the root dentin surface were measured. This technique enables the direct measurement of root dentin pH at specific locations of the root.

Dentin cavities were created at two positions on the root: the middle third and the apical third, to investigate the effects of variations in the size and number of dentinal tubules. Additionally, this investigation included an examination of how dentin depth influences the diffusion of hydroxyl ions, which is aligned with the study's objectives. Thus, cavities of varying depths were prepared in the middle third. However, only one cavity was created in the apical third due to the insufficient thickness of the root dentin in this area, which precluded the preparation of a cavity with the intended depth.

According to the result of this study, the pH changes in Biodentine group showed the highest pH at 2 hours after the root canal was filled. In contrast, the ProRoot MTA and Bio-MA groups exhibited their highest pH at 1 day. Previous studies have indicated that the setting time of calcium silicate-based cement influences the duration when the pH reaches its peak. ProRoot MTA and Bio-MA have the same main components: tricalcium silicate and dicalcium silicate. These components are the main precursors of the setting reaction. Bio-MA includes the addition of calcium chloride in the liquid component to reduce setting time [9, 22]. On the other hand, Biodentine's main component is pure tricalcium silicate, with added polycarboxylate as a water-reducing agent and calcium chloride, which acts as a setting accelerator [23]. During the hydration reaction of these cements, hydroxyl ions are the primary product released from calcium hydroxide in an acceleration phase of the reaction. This occurs after the initial setting and leads to an increase in pH until it reaches the highest value [24]. Given that Biodentine has a faster initial setting time compared to ProRoot MTA and Bio-MA [22, 23, 25], these studies observed that

the highest pH in root dentin filled with Biodentine occurred earlier than in the other groups. This finding aligns with the demonstrated faster peak pH value of the Biodentine group in this study. After reaching their respective peak pH values, each group exhibited a slight decrease in pH, following similar patterns, and then stabilized for the fourth week. This phenomenon could be attributed to the continuous release of ionic components from the residual calcium silicate powder after the post-acceleration phase of the hydration reaction [8, 26]. Consequently, the material sustained the leaching of ionic components throughout the test period [27, 28].

When comparing the calcium silicate-based cements, our study found comparable highest pH values among Biodentine (pH 8.58-9.07), ProRoot MTA (pH 8.86-9.12), and Bio-MA (pH 8.92-9.18). However, after reaching the highest pH, the pH values of Biodentine group decreased and became lower than those of the ProRoot MTA and Bio-MA groups, and the constant pH value was significantly lower than Bio-MA. This result differs from previous studies that reported a higher pH in Biodentine than in ProRoot MTA [29-31]. Furthermore, when comparing Biodentine with ProRoot MTA, Biodentine could reach a higher peak pH and still maintain a higher pH level than ProRoot MTA [29]. The difference in these results between studies might be due to different pH measurement techniques that were used.

No difference in the pH values was observed between the location of the inner middle and apical portion. This finding contrasts with previous studies that reported lower pH values at the apical portion compared to other levels [11,14,16]. The disparity may be attributed to variations in the tooth type and age used in each study. The majority of teeth included in our study were collected from young patients who had their premolars extracted for orthodontic treatment. As the dentinal tubule size tends to decrease with age, younger teeth would have larger dentinal tubules both in the middle and apical portions [32,33]. Consequently, the difference in pH values between these two root levels may not be significantly represented in our study. Furthermore, the different thickness of the dentin also affects the pH values. In our study, at the middle root level, pH at 1mm from the root canal wall was significantly lower than at 0.5 mm from the root canal wall. This discrepancy may be attributed to the buffering capacity of dentin, where hydroxyl ions are absorbed into the hydrated layer of dentin [11]. Additionally, the outer root dentin has fewer dentinal tubules than the inner dentin [34]. Therefore, the pH value of the root dentin decreased as the measurement moved further away from the root canal.

This in vitro study revealed the highest pH values in root dentin following root canal filling with ProRoot MTA, Bio-MA and Biodentine ranged from 9.07 to 9.18. This alkaline pH range may create an unsuitable environment for residual microorganisms within the root canal. Previous research has highlighted the impact of environmental pH on the growth and metabolism of certain predominant endodontic pathogens. For instance, *Porphyromonas gingivalis* tends to grow in neutral pH ranges (6.5-7.0) and exhibits optimum proteolytic activity at pH 7.5 to 8.0. Similarly, *Prevotella intermedia* and *Fusobacterium nucleatum* grow well within pH ranges of 5.5-7.0, with the most suitable environment for proteolytic activity of *Prevotella intermedia* being at pH 7 [35,36]. Therefore, while the alkaline pH values identified in this study might eliminate some remnant strains within the root canal and dentinal tubules,

they may not be sufficiently high to impact other bacterial species such as *E. faecalis*, which can tolerate very high alkaline environments ranging from 9 to 11 [37].

The pH changes of root dentin, shifting towards higher alkaline levels after filling with these calcium silicate-based cements, were notably observed at a distance of 1 mm from the root canal wall. This suggests that the diffusion of hydroxyl ions through dentinal tubules can extend to the root surface, as same as the action of calcium hydroxide medication, potentially establishing an alkaline environment at the external root surface. Across all materials, the alkaline pH of root dentin remained constant for the fourth week, indicating that calcium silicate-based cements can consistently release hydroxyl ions over an extended period. These significant findings may offer advantages in the management of external inflammatory root resorption. A study by Trope in 1995 concluded that complete cemental repair was seen in long-term (approximately 12 weeks) calcium hydroxide medication in the treatment of external inflammatory root resorption compared to short-term (1 week) medication. This is attributed to the prolonged treatment addressing persistent infection in dentinal tubules, reducing clastic activity, and creating a conductive environment for the healing process [38]. Several case reports have used calcium silicate-based cements as root filling materials after calcium hydroxide treatment without long-term medication to repair irregularities of the root canal and cease the resorptive process, with favorable treatment outcomes [39, 40]. Our results suggest that ProRoot MTA, Bio-MA and Biodentine can be applied as a root canal filling material after routine dressing with calcium hydroxide in the point of maintaining the high pH for a longer period in treatment of external inflammatory root resorption.

Conclusion

Under the conditions of this study, significant pH changes were observed in root dentin following root canal filling with each calcium silicate-based cement over a 4-week period. The highest pH values of root dentin filled with ProRoot MTA (9.12), and Bio-MA (9.18) were noted after 1 day at all root levels. In contrast, in Biodentine group, the highest pH value (9.07) was observed at 2 hours at all root levels except the outer middle root level. Notably, nearly all pH values at the outer middle root level in each calcium silicate-based cement were lower than the pH values at the apical and inner middle root levels.

Acknowledgements

The authors thank Assist. Prof. Dr. Chulaluk Komoltri and Assist. Prof. Sittichoke Osiri for their assistance in statistical analysis.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Conflict of Interest

The authors declare that they have no conflict of interest.

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