



Quality of Root Canals Filled with a Calcium Silicate-Based Sealer using Different Placement Methods: A Micro-CT Study

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Research Article

Abstract

Objective : This study aimed to compare the volumes of voids and gaps in root canals fillings obtained with the single-cone technique using a calcium silicate-based sealer placed by different methods, as assessed by micro-computed tomography (micro-CT).

Materials and Methods : Sixty extracted mandibular premolars with oval-shaped canals were prepared using nickel-titanium rotary instruments to an apical size of 40/.04 and randomly assigned to three groups according to the sealer placement methods: ST, single-cone technique with a disposable tip; STU, single-cone technique with a disposable tip and ultrasonic activation; and STL, single-cone technique with a disposable tip and a lentulo spiral (n= 20 per group). Each obturated tooth was scanned with micro-computed tomography to evaluate the presence of voids and gaps. The percentage volume of voids and gaps was calculated at the coronal, middle and apical levels. Data were statistically analyzed using the Kruskal-Wallis test and linear mixed model with Bonferroni adjustment at a 5% significance level.

Results : The STL group had the highest total percentage volume of voids (3.971%), whereas the ST group had the highest total percentage volume of gaps (1.428%). Across the entire canal, no significant between-group differences were observed for the percentage volume of either voids or gaps ($p>0.05$). At the coronal level, the STL group exhibited a significantly greater percentage volume of voids than the other groups ($p<0.05$), and within the STL group the coronal was significantly higher than the middle and apical levels ($p<0.05$). No significant differences in percentage volume of gaps were detected between groups or among canal levels ($p>0.05$).

Conclusion : Within the limitation of this study, no significant differences were found in overall void and gap formation among the three sealer placement methods. However, the use of a lentulo spiral in oval-shaped canals was associated with the highest void volume at the coronal level.

Keywords: Calcium silicate/ Filling quality/ Micro-computed tomography/ Root canal obturation

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Introduction

The primary objective of root canal treatment is to prevent and manage apical periodontitis caused by bacterial infection of the root canal system, as chemomechanical debridement alone cannot completely eradicate microorganisms from the root canal^{1,2}. Root canal obturation aims to entomb residual microorganisms and provide a hermetic seal, thereby preventing reinfection due to fluid leakage into the root canal system^{3,4}.

During obturation, an endodontic sealer is used in conjunction with gutta-percha to fill the root canal system. The main functions of sealers are to seal the root canal, entomb remaining bacteria, and fill anatomical irregularities within the root canal⁵. However, the amount of sealer should be minimized as many endodontic sealers exhibit high solubility and shrinkage, which may compromise their sealing ability⁶⁻¹¹.

Currently, calcium silicate-based sealers are widely used for root canal obturation, with iRoot SP (Innovative BioCeramix Inc, Vancouver, Canada) regarded as the main representative of this group because it has been extensively studied and is frequently employed as a reference material in research. This sealer exhibits several advantageous properties, including slight expansion upon setting rather than shrinkage¹², antimicrobial activity^{13,14}, high flow¹⁵⁻¹⁷, and excellent biocompatibility and bioactivity^{16,18,19}. According to the manufacturer's instructions, calcium silicate-based sealers are placed into the root canal using a disposable tip or hand file and obturated with single-cone technique. In this technique, the sealer serves as the primary filling material, while the gutta-percha cone acts as a carrier to facilitate sealer placement throughout the canal. Consequently, this approach may increase the likelihood of void and gap formation. Various sealer placement methods have been proposed to minimize these defects, as voids and gaps in the root

canal fillings can lead to porosity, compromise filling quality, provide niches for microbial habitation, and allow the bacterial toxin through the filled root canal²⁰.

However, studies evaluating the quality of root canal fillings using calcium silicate-based sealers with different placement techniques remain limited. In a previous study, Kim et al.²¹ reported no significant differences in filling quality when Endoseal MTA was placed using an intracanal tip with or without ultrasonic activation, based on both the proportion of void-containing sections and the void volume percentage assessed by micro-CT. Nevertheless, few investigations have provided detailed analysis of whether different sealer placement techniques influence the occurrence and distribution of voids and gaps at various levels within the root canal.

Microcomputed tomography (micro-CT) is widely used to evaluate sealing ability and obturation quality, as it provides a highly accurate and nondestructive assessment²². This method allows precise detection of voids within fillings and quantification of void and gap volumes²³. Therefore, the aim of this study was to compare the volume of voids and gaps in root canal fillings obtained with a calcium silicate-based sealer using three different placement techniques, and to evaluate differences in void and gap formation among placement methods and canal levels, as assessed by micro-CT.

Materials and Methods

Sample preparation

The study protocol was approved by the Ethics Committee of the Faculty of Dentistry/Faculty of Pharmacy, Mahidol University (reference no. MU-DT/PY-IRB 2020/DT168), Bangkok, Thailand.

The sample size was determined using *nQuery Advance* version 8.5.2 (Statistical Solutions Ltd., Boston, MA, USA), based on the F-test family for

one-way ANOVA. The calculation was performed with an assumed effect size of 0.194²¹, a power ($1-\beta$) of 80%, and a significance level (α) of 0.05. This analysis indicated that a minimum of 20 specimens per group was required. Accordingly, a total of 60 specimens (n=20 per group, 3 groups) was included in this study.

Sixty single-rooted mandibular premolars without caries, root resorption, or fractures were collected and stored in 0.1% thymol solution. Each tooth was examined for variations in root canal anatomy, and the canal width was measured in both the buccolingual and mesiodistal directions at 5 mm from the apex. Only teeth with straight single canals (Vertucci's type I [1-1] configuration) and oval-shaped canals, defined as having a buccolingual-to-mesiodistal ratio greater than or equal to 2:1, were included.

All teeth were decoronated and standardized to a length of approximately 12 mm from the root tip using a high-speed fissure diamond bur. A size 10 K-file (Dentsply Maillefer, Ballaigues, Switzerland) was inserted into the root canal until reaching the apical foramen, and the working length was determined by subtracting 1mm from this length. A glide path was established using a size 15 K-file (Dentsply Maillefer, Ballaigues, Switzerland) at the working length. Root canals were prepared with Race Ni-Ti rotary instruments (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland) to an apical size 40/.04. Irrigation was performed with 2.5% sodium hypochlorite (NaOCl) after each file, and rotary instruments were replaced after every 10 uses. Following canal enlargement, irrigation was performed with 3 ml of 17% ethylenediaminetetraacetic acid (EDTA) (Endo Clean, M Dent, Bangkok, Thailand) for 1 minute, followed by a final rinse with 5 ml of 2.5% sodium hypochlorite. Apical patency was confirmed with a size 10 K-file, and canals were dried with paper points.

Subsequently, all specimens underwent micro-CT imaging to obtain the baseline root-canal volume. Stratified randomization was then performed on the basis of these measurements: teeth were

ranked by canal volume and divided into three strata (low, medium, high). Within each stratum, a computer-generated sequence allocated specimens in a 1:1:1 ratio to the ST, STU, or STL groups. In total, 60 teeth were assigned (n=20 per group) according to the designated sealer placement technique.

Sealer placement

Single-cone technique with disposable canal tip (ST group): The sealer iRoot SP, Innovative BioCeramix, Vancouver, Canada) was delivered into the canal using a premixed syringe with a disposable tip, approximately 8 mm short of the working length, as recommended by the manufacturer. A size 40/.04 gutta-percha cone (Dentsply Maillefer, Ballaigues, Switzerland) was coated with sealer 4 mm from the tip and gently inserted into the canal to the working length.

Single-cone technique with disposable canal tip and ultrasonic activation (STU group): The sealer was delivered into the canal approximately 4 mm short of the working length using a premixed syringe with a disposable tip. An ultrasonic tip (Tip #1, Satelec, Mount Laurel, NJ, USA) connected to an ultrasonic device (P-5 Newtron XS; Satelec, Mount Laurel, NJ, USA) was set at "8" in the yellow code. The gutta-percha cone (size 40/.04) was coated with sealer 4 mm from the tip. The ultrasonic tip was then applied to a cotton plier holding the gutta-percha cone 20 mm from its tip, and the cone was gently inserted to the working length under continuous ultrasonic activation for 2–3 seconds.

Single-cone technique with disposable canal tip and lentulo spiral (STL group): The sealer was delivered into the canal approximately 4 mm short of the working length using a premixed syringe with a disposable tip. A lentulo spiral (size 35) was then inserted into the root canal 1 mm short of the working length, gradually withdrawn while rotating at 900 rpm with 1 N-cm torque. Subsequently, a size 40/.04 gutta-percha cone was coated with sealer 4 mm from the tip and gently inserted into the canal to the working length.

The coronal end of the gutta-percha cone was cut at the canal orifice using an electrical heat carrier (System B Heat Source, SybronEndo, Orange, CA, USA). Excess sealer was removed with a moist cotton pellet. All specimens were stored in a container at 37 °C and 100% humidity for 7 days to allow complete setting of the sealer.

Micro-computed tomography evaluation

A micro-CT scanner (Skyscan 1173, Bruker MicroCT, Kontich, Belgium) was used to scan the specimens. The micro-CT system had an isotropic pixel size of 8 µm. The X-ray source voltage was set at 80 kV, with a beam current of 100 µA, and aluminum filter thickness of 1 mm. The rotation increment was 0.4° per step, with an exposure time of 600 ms. To minimize ring artifacts, detector air calibration was performed before each scan. Additional settings included beam-hardening correction and adjustment of contrast limits according to the manufacturer's instructions.

Reconstructed images were obtained using the NRecon software (SkyScan), and void and gap volumes were analyzed with CTAn software (v1.16. Bruker Micro CT). In this study, a void was defined as a pore completely enclosed within the filling material (within the sealer or between the sealer and gutta-percha) without communication with dentin, whereas a gap was defined as a pore directly communicating with the dentin–sealer interface (Figure 1).

For the calculation of void and gap volumes, the original grayscale images were processed with a Gaussian low-pass filter to reduce noise. Automatic segmentation thresholds were applied to differentiate dentin, gutta-percha, voids, gaps, and sealer. Binarization was performed to generate black/white images, and a region of interest was selected for each slice to calculate void and gap volumes. Each specimen was divided into three

regions: apical (0-4 mm from the root apex), middle (4-8 mm), and coronal (8-12 mm). The percentages of voids (%V) and gaps (%G) were calculated using the following formulas: $\%V = V_v / (V_v + V_g + V_f) \times 100$ and $\%G = V_g / (V_v + V_g + V_f) \times 100$. V_f is the volume of the filling material, V_g is the gap volume and V_v is the void volume. Three-dimensional reconstruction of the filling was generated using CTVol software (SkyScan) to visualize overall obturation quality (Figure 2).

Statistical analysis

Statistical analysis was performed using STATA¹⁷ (StataCorp LLC, Texas, USA). A p -value < 0.05 was considered statistically significant. The Shapiro-Wilk test was used to assess data distribution, which indicated non-normality; therefore, the Kruskal-Wallis test was applied to evaluate differences in percentage volumes of $Voids_{(total)}$ and $Gaps_{(total)}$ among the groups. The effects of placement methods and the levels were analyzed using a linear mixed model with Bonferroni adjustment.

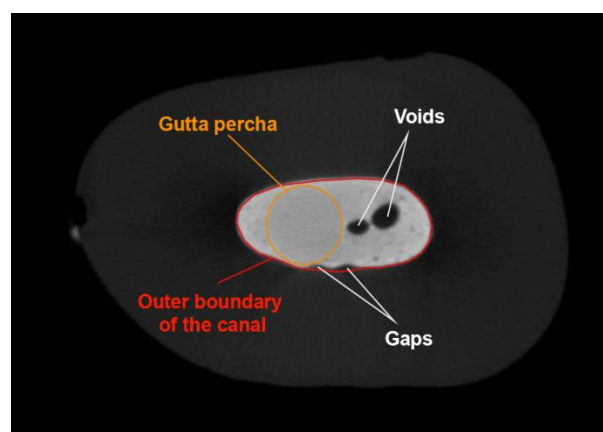


Figure 1 Representative micro-computed tomography (micro-CT) cross-section of an obturated canal. The outer canal boundary is delineated in red. The gutta-percha core is indicated, with voids (closed pores) and gaps (open pores at the dentin–sealer interface) labeled.

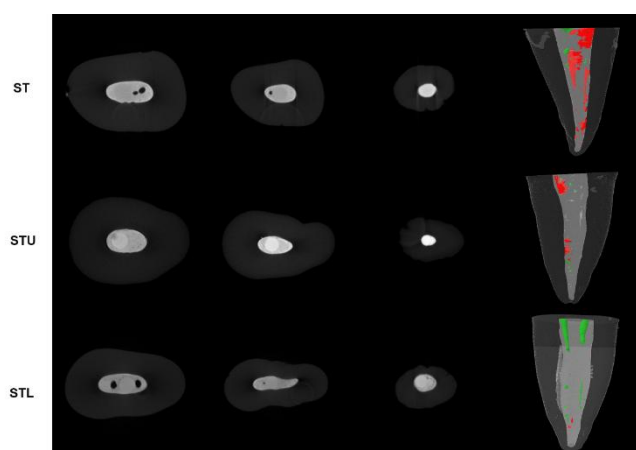


Figure 2 Two-dimensional axial slices (coronal to apical, left to right) and three-dimensional reconstructions of obturated roots for each group. In the 3D renderings, gutta-percha and sealer are shown in white, gaps in red, and voids in green. Abbreviations: ST; Single-cone technique with disposable canal tip, STU; Single-cone technique with disposable canal tip and ultrasonic activation, STL; Single-cone technique with disposable canal tip and lentulo spiral.

Results

The median percentage volumes of root canal voids and gaps in the total root canal are presented in Table 1. The highest percentage of voids was observed in the STL group (3.971%), while the highest percentage of gaps was observed in the ST group (1.428%). However, no significant differences were found in the percentage volumes of voids or gaps in the total root canal (%Void_(total) and %Gap_(total)) among the three placement methods ($p > 0.05$).

The percentage volumes of voids at the coronal, middle, and apical levels are shown in Table 2. The STL group demonstrated a significantly higher percentage volume of voids at the coronal levels (4.702%, $p < 0.05$) compared with the other groups. In

contrast, no significant differences were observed among the groups at the middle or apical level ($P > 0.05$). Within the STL group, significant differences were observed between the coronal level and the other levels ($p < 0.05$), whereas no significant differences were found among the levels in the ST and STU groups ($p > 0.05$).

The percentage volumes of gaps at the coronal, middle and apical levels are presented in Table 3. The ST group exhibited the highest percentage volume of gaps at the middle level (2.26%). Nonetheless, no significant differences were observed in percentage volumes of gaps among the groups or levels ($p > 0.05$).

Table 1 Percentage volume of total root canal voids and gaps in the ST, STU, and STL.

Variables	Group ST Median (Q1-Q3), (Min-Max)	Group STU Median (Q1-Q3), (Min-Max)	Group STL Median (Q1-Q3), (Min-Max)	p-value*
%Void _(total)	1.902 (1.121-4.549), (0.261-8.221)	2.128 (0.277-3.331), (0.0490-8.196)	3.971 (1.877-6.311), (0.054-16.673)	0.086
%Gap _(total)	1.428 (0.290-2.290), (0.011-13.361)	0.394 (0.128-0.978), (0.001-3.102)	0.791 (0.279-1.985), (0.001-8.125)	0.181

Values are presented as median (Q1-Q3), with minimum and maximum in parentheses.

*Statistical evaluation was performed using a Kruskal-Wallis test.

Abbreviations: ST; Single-cone technique with disposable canal tip, STU; Single-cone technique with disposable canal tip and ultrasonic activation, STL; Single-cone technique with disposable canal tip and lentulo spiral.

Table 2 Percentage volume of voids at coronal, middle, and apical levels in ST, STU, and STL.

	Group ST Median (Q1-Q3) (Min-Max)	Group STU Median (Q1-Q3) (Min-Max)	Group STL Median (Q1-Q3) (Min-Max)
Coronal	2.134 ^{aA} (1.433-4.768), (0.301-11.923)	2.622 ^{aA} (0.327-4.257), (0.055-11.430)	4.702 ^{b,B} (2.133-9.346), (0.059-26.932)
Middle	1.074 ^{aA} (0.147-2.538), (0.001-7.425)	0.465 ^{aA} (0.175-1.372), (0.001-4.720)	1.006 ^{aA} (0.189-3.312), (0.015-6.495)
Apical	0.225 ^{aA} (0.042-1.207), (0.001-10.659)	0.084 ^{aA} (0.002-0.876), (0.001-8.769)	0.566 ^{aA} (0.148-1.630), (0.001-3.519)

Values are presented as median (Q1–Q3), with minimum and maximum in parentheses. Different uppercase letters within the same column indicate statistically significant differences among root levels ($p < 0.05$). Different lowercase letters within the same row indicate statistically significant differences among groups ($p < 0.05$). Statistical evaluation was performed using a linear mixed model with Bonferroni adjustment. Abbreviations: ST; Single-cone technique with disposable canal tip, STU; Single-cone technique with disposable canal tip and ultrasonic activation, STL; Single-cone technique with disposable canal tip and lentulo spiral.

Table 3 Percentage volume of gaps at coronal, middle, and apical levels in ST, STU, and STL.

	Group ST Median (Q1-Q3) (Min-Max)	Group STU Median (Q1-Q3) (Min-Max)	Group STL Median (Q1-Q3) (Min-Max)
Coronal	0.574 ^{aA} (0.012-2.158), (0.001-12.514)	0.355 ^{aA} (0.028-0.822), (0.001-5.045)	0.317 ^{aA} (0.052-1.309), (0.001-10.587)
Middle	2.260 ^{aA} (0.003-3.522), (0.001-19.471)	0.011 ^{aA} (0.002-0.403), (0.001-8.724)	0.593 ^{aA} (0.002-2.519), (0.001-10.544)
Apical	0.123 ^{aA} (0.005-1.813), (0.001-6.517)	0.003 ^{aA} (0.001-0.063), (0.001-7.965)	0.340 ^{aA} (0.004-2.256), (0.001-7.603)

Values are presented as median (Q1–Q3), with minimum and maximum in parentheses. Different uppercase letters within the same column indicate statistically significant differences among root levels ($p < 0.05$). Different lowercase letters within the same row indicate statistically significant differences among groups ($p < 0.05$). Statistical evaluation was performed using a linear mixed model with Bonferroni adjustment. Abbreviations: ST; Single-cone technique with disposable canal tip, STU; Single-cone technique with disposable canal tip and ultrasonic activation, STL; Single-cone technique with disposable canal tip and lentulo spiral.

Discussion

In endodontics, there is a general consensus that the quality of each treatment step is closely associated with the likelihood of apical healing. Among these steps, root canal obturation plays a particularly critical role, as it seals the canal walls and entombs any remaining bacteria within the root canal system. Voids (closed pores), which are internal air pockets capable of entrapping bacteria, and gaps (open pores), which create pathways for microbial and toxin penetration into the root canal system^{12, 24} are considered one of the methods for evaluating obturation quality. Some studies have reported that poor root canal filling quality (defined as root fillings terminating more than 2 mm short of the

radiographic apex, or being grossly overfilled, unfilled, or containing voids with inadequate density) may act as a prognostic determinant of endodontic treatment failure.²⁵ Root canal obturation using the single-cone technique with a sealer-based approach often results in a substantial amount of sealer, thereby increasing the likelihood of voids and gaps. This observation formed the basis of the present study, which aimed to investigate whether different sealer placement methods affect the occurrence of these defects. Voids and gaps were analyzed separately because they may have distinct impacts on treatment outcomes.

The results of this study showed no significant differences in the total percentage volume of voids or gaps among the different sealer placement methods. These findings are consistent with those of Kim et al.²¹, who reported no significant differences in void formation (referring to both voids and gaps) when using a disposable canal tip with or without ultrasonic activation, as assessed by micro-CT. This outcome may be explained by the favorable physicochemical properties of calcium silicate-based sealers, particularly their excellent flowability and adaptation to the root canal walls, which could minimize discrepancies in void and gap formation when evaluated across the entire root canal system.

However, when analyzing void formation at different root canal levels, the group that using a lentulo spiral exhibited a significantly higher percentage of voids at the coronal level compared with other techniques. This may be attributed to the rotation speed of the lentulo spiral (900 rpm) combined with the liquid consistency of the sealer, which could have entrapped air during placement. However, previous studies have reported mixed results regarding the effectiveness of the lentulo spiral. Guinesi et al.²⁶ reported that using a lentulo spiral to place AH Plus sealer with the single-cone technique produced fewer voids than placement using a file or gutta-percha. On the other hand, Nabavizadeh et al.²⁷ reported no significant difference in void percentage when placing AH26 sealer was placed a lentulo spiral compared with other methods (file, gutta-percha, and ultrasonic file) in root canals filled using lateral condensation technique. Therefore, the increased coronal voids in our study may not be solely attributable to the lentulo spiral but may also relate to the oval shape of the root canal in this region. Several studies have highlighted the influence of canal shape on void formation. Celikten et al.²⁸ reported that voids were

significantly more common at the coronal level than at the apical level due to canal morphology, regardless of sealer used. Similarly, Huang et al.²⁹ found that the volume of close pores was highest at the coronal level when using either AH Plus or EndoSequence BC sealer, as assessed by micro-CT. Collectively, the potential for air entrapment associated with lentulo spiral-assisted sealer placement, combined with the larger volume of the oval-shaped coronal canal, may synergistically account for the higher incidence of voids observed at this level compared with other techniques and canal levels.

Regarding gap formation, this study reported total gaps percentage ranging from 0.39% to 1.428%, consistent with previous findings. Milanovic et al.²⁴ observed approximately 4% open porosity in root canals filled with EndoSequence BC sealer. In this study, no significant differences in total gap volume were detected among placement techniques, including in oval-shaped canal filled with iRoot SP. Likewise, no significant differences were observed between groups at the same canal level, or across different levels within group. The high flowability of calcium silicate-based sealers likely facilitated close adaptation to the root canal walls. Although all three placement methods resulted in comparable gap formation, ultrasonic activation tended to produce fewer gaps, particularly at the middle and apical levels, possibly due to enhanced sealer distribution and adaptation.

Based on these findings, the manufacturer-recommended single-cone technique using a disposable tip appears to be a simple and effective method for sealer placement, minimizing the number of instruments required and reducing operator variability, while yielding void and gap formation comparable to other adjunctive loading approaches. However, in oval-shaped root canals,

where interfacial gap formation may be of particular concern, ultrasonic activation may be a preferable adjunct, as it has been shown to reduce the occurrence of voids and gaps.

Although micro-CT is a non-destructive method that enables repeated analysis of the same sample, its ability to detect voids and gaps is limited by the scanner's resolution. Voids and gaps smaller than 10–20 µm may remain undetected²⁴, indicating that some voids and gaps might not have been identified. In addition, the present study used teeth with straight and oval-shaped root canals. In other root canal morphologies, such as teeth with curvatures or isthmuses, the outcomes may differ from those observed in this study.

Conclusion

Within the limitations of this study, no significant differences were observed in the formation of voids and gaps among the three sealer placement techniques in root canals filled with a calcium silicate-based sealer. However, the use of a lentulo spiral for placing the sealer in oval-shaped root canals resulted in the highest percentage of void volume at the coronal level of the root canal filling.

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การศึกษาคุณภาพการอุดคลองรากฟันด้วยซีลเลอร์ ชนิดแคลเซียมซิลิเกตที่มีวิธีการใส่แตกต่างกัน โดยวิธีไมโคร-คอมพิวเทตโทโมกราฟี

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บทความวิจัย

บทคัดย่อ

วัตถุประสงค์: การศึกษานี้มีวัตถุประสงค์เพื่อเปรียบเทียบปริมาณของรูพรุนและช่องว่างในวัสดุอุดคลองรากฟันที่อุดด้วยเทคนิคซีล-โคนร่วมกับการการใช้ซีลเลอร์ชนิดแคลเซียมซิลิเกต โดยวิธีการใส่ซีลเลอร์ที่แตกต่างกันด้วยภาพรังสีไมโคร-คอมพิวเทตโทโมกราฟี

วัสดุอุปกรณ์และวิธีการ: ใช้ฟันกรามน้อยล่างที่มีคลองรากรูปร่างรี จำนวน 60 ซี่ ทำการขยายคลองรากฟันด้วยตะไบระบบนิกเกิล-ไทเทเนียมแบบหมุนด้วยเครื่องกลจนถึงขนาด 40/04 จากนั้นแบ่งตัวอย่างออกเป็น 3 กลุ่มตามวิธีการใส่ซีลเลอร์ ได้แก่ (1) การใส่ซีลเลอร์ด้วยเข็มฉีดยา (2) การใส่ซีลเลอร์ด้วยเข็มฉีดยาร่วมกับการกระตุ้นด้วยอัลตราโซนิค และ (3) การใส่ซีลเลอร์ด้วยเข็มฉีดยาร่วมกับเลเซอร์ไดรฟ์ หลังจากการอุดคลองรากฟัน นำตัวอย่างเข้าสู่กระบวนการถ่ายภาพรังสีไมโคร-คอมพิวเทตโทโมกราฟี เพื่อตรวจวัดร้อยละปริมาตรรูพรุน และช่องว่างในระดับคลองรากส่วนต้น ส่วนกลาง และส่วนปลาย ข้อมูลถูกวิเคราะห์ทางสถิติด้วยการทดสอบครัสคัล-วัลลิส และแบบจำลองเชิงเส้นผสม พร้อมการปรับค่าบอนเพอโรนีที่ระดับนัยสำคัญ 0.05

ผล: กลุ่ม STL มีร้อยละปริมาตรรูพรุนรวมสูงสุด (3.971%) ขณะที่กลุ่ม ST มีร้อยละปริมาตรช่องว่างรวมสูงสุด (1.428%) เมื่อประเมินตลอดทั้งคลองราก ไม่พบความแตกต่างระหว่างกลุ่มทั้งร้อยละปริมาตรของรูพรุนและช่องว่างอย่างมีนัยสำคัญทางสถิติ ใน ($p>0.05$) ที่ระดับคลองรากส่วนต้น กลุ่ม STL มีร้อยละปริมาตรรูพรุนสูงกว่ากลุ่มอื่นอย่างมีนัยสำคัญ ($p<0.05$) และภายในกลุ่ม STL ระดับคลองรากฟันส่วนต้นมีร้อยละปริมาตรรูพรุนสูงกว่าระดับส่วนกลางและส่วนปลายอย่างมีนัยสำคัญ ($p<0.05$) ไม่พบความแตกต่างอย่างมีนัยสำคัญ ของร้อยละปริมาตรช่องว่างระหว่างกลุ่มหรือระหว่างระดับของคลองราก ($p>0.05$)

บทสรุป: ภายใต้อำนาจจำกัดของการศึกษานี้ การอุดคลองรากฟันที่มีรูปร่างรีด้วยเทคนิคซีล-โคนร่วมกับการใส่ซีลเลอร์ทั้งสามวิธี ให้ผลการเกิดรูพรุนและช่องว่างไม่แตกต่างกันเมื่อพิจารณาภาพรวมของทั้งคลองรากฟัน อย่างไรก็ตามการใส่ซีลเลอร์ด้วยเลเซอร์ไดรฟ์ในคลองรากฟันรูปร่างรี มีแนวโน้มทำให้เกิดรูพรุนสูงสุดบริเวณคลองรากส่วนต้น

คำไชรหัส : การอุดคลองรากฟัน/ คุณภาพการอุด/ แคลเซียมซิลิเกต/ ไมโคร-คอมพิวเทต โทโมกราฟี

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