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Original Article

Assessment of isthmus filling using two obturation techniques performed by students with different levels of clinical experience

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KEYWORDS
Dental education;
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Abstract *Background/purpose:* Root canal filling is a necessary skill for dental students and an important aspect of endodontic education. This study aimed to evaluate the effect of students' clinical experiences on isthmus filling using different techniques and sealers.

Materials and methods: One hundred eight three-dimensional-printed resin replicas of isthmus were divided into six groups and either continuous wave of condensation (CWC) or single-cone obturation (SC) was performed. One of three sealers (AH Plus Jet®, GuttaFlow2, iRoot SP) was used together with a size-fitted gutta-percha master cone. All the obturations were completed by students with three different levels of clinical experience including senior postgraduate students (SPS), junior postgraduate students (JPS), and undergraduate students (US). The percentages of filled areas (PFA) at 2, 4, 6, and 8 mm from the apex were analyzed using a light microscope. Data were analyzed using the Mann-Whitney *U* test or Kruskal-Wallis 1-way ANOVA with Dunn's tests ($\alpha = 0.05$).

Results: The CWC group exhibited a higher PFA than the SC group ($P < 0.05$). The PFA was higher in the SPS group than in the JPS group or the US group with CWC ($P < 0.05$). The three clinical experience groups showed similar PFAs with SC ($P > 0.05$); however, when using SC with iRoot SP, the PFA was higher than with either of the other two sealers ($P < 0.05$).

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Conclusion: CWC was found to be technique-sensitive and required clinical training. With SC, clinical experience did not improve the quality of isthmus filling without additional training. CWC was superior to SC for type IV isthmuses. When using SC, better filling quality was obtained with a bioceramic sealer.

Introduction

Root canal treatment is the most common therapeutic method for pulp and periapical diseases, and it is also one of the most basic and common courses during clinical training in dental education. Root canal filling is one of the key steps in root canal treatment and insufficient obturation may lead to treatment failure.[1] It has been reported that the quality of root canal fillings depends not only on the selection of appropriate techniques and materials, but also on the skills of the operator.[2–5] Therefore, it is of great importance to train students in obturation techniques during endodontic education.

Lateral condensation and warm vertical compaction are the most classic and commonly-used obturation techniques in dental clinics. However, the two techniques consist of multiple steps, which are tedious and time-consuming.[6] At present, with the rapid development of bioceramic sealers, single-cone obturation (SC) is gaining attention due to its simple steps, lack of reliance on special equipment and short operation time. However, it is unknown whether the seemingly simple filling technique is easy to learn or requires training, and whether the technique can be used to fill complex root canal morphologies. In addition, it should be noted that when performing SC, the proportion of sealer in the filling materials is significantly increased. Consequently, higher sealer performance is required to ensure sufficient obturation and long-term sealing.

The isthmus is a complex morphological structure in the root canal system. Yin analyzed the three-dimensional morphology of 248 M using micro-computed tomography (micro-CT) and found that 75.4% of specimens had isthmus areas.[7] The isthmus is variable with a complex narrow structure that is difficult to fill tightly.[2,8] Previous studies showed that obturation technique is an important factor affecting the filling quality of complex morphological structures, such as C-shaped canals, band-shaped isthmuses, and flattened canals.[2,3,9] Sufficient obturation of the isthmus not only requires an intimate knowledge of the anatomy of the isthmus, but also competent skills in obturation techniques. Training students to obturate root canals with isthmuses is necessary for successful root canal treatment, as well as to enable students to develop into qualified general dentists and endo-specialists.

The aim of the present study was to evaluate the effects of students' clinical experience on isthmus filling using different techniques and sealers. Three-dimensional (3D)-printed root canal model containing a type IV isthmus[7] was adopted. In Yin's study, isthmuses were classified into four types based on the boundary characteristics: isthmus with roof (Type I), isthmus with floor (Type II), band-shaped isthmus (Type III), and isthmus without boundary (Type IV).[7] Type IV isthmus was without a boundary, which was more common in mandibular molars with a complete connection between the two canals from the pulp chamber to the apex.[7] The students with different levels of clinical experience were required to fill the root canals using the continuous wave of condensation (CWC) or SC with three different sealers. The hypotheses for the study were: (1) when using SC, the clinical experience of students would not have significant effect on the quality of isthmus filling; and (2) the quality of isthmus filling would not be influenced by the choice of filling techniques and sealers.

Materials and methods

Participant selection

This study was exempted from oversight by the Institutional Review Board of Peking University (PKUSSIRB-202277008-exemption). In order to evaluate the quality of root canal filling performed by students with different levels of clinical experience using different obturation techniques, students with three different levels of clicinal experience from Department of Cariology and Endodontology, Peking University were selected by referring to a previous literature.[10] Group undergraduate students (US) had no clinical experience in root canal treatment. They were trained and practiced cold lateral condensation and CWC on extracted human teeth in a preclinical setting. Group junior postgraduate students (JPS) had one to two years of clinical experience in root canal treatment, and Group senior postgraduate students (SPS) had three to four years of clinical experience in root canal treatment. The postgraduate students with clinical training were permitted to use CWC after performing root canal fillings on ten anterior teeth or premolars and 10 M using cold lateral condensation in clinical practice. No students were trained in SC. All the three group students received special training and consistency evaluation of filling techniques, and they were able to represent students with different levels of clinical experiences.

Manufacture of the 3D-printed root canal isthmus model

The design and manufacture of the 3D-printed root canal isthmus model is shown in Fig. 1. Based on our previous study, a root canal system containing two root canals and an isthmus was selected, which was classified as Yin's type IV isthmus.[7] Based on micro-CT data, an original root canal

model was printed using transparent resin material (VeroClear OBJ-04055, Stratasys, Rehovot, Israel) on an Objet30 pro printer (Stratasys) with a precision of 0.016 mm. The two root canals were prepared using HyFlex CM files (Coltene/Whaledent, Altstatten, Switzerland) (working length [WL], 13.5 mm; taper, 0.04; master apical file, #30). The prepared model was then scanned using a micro-CT system (Inveon MM CT, Siemens AG, Munich, Germany) with a voxel size of 8.9 μm. After data processing, the final model with the prepared root canal system was printed. The d_{min}[7] of the isthmus of the final printed model was 0.066 mm.

The support materials (Support 706, Stratasys) were removed from the main canals using an ISO size #20 K-file, and further removed from the isthmus by passive ultrasonic irrigation (P5 Newtron, Satelec, Acteon, France) with alkali solution (1% NaOH and 2% Na_2SiO_3) and distilled water. Each canal was pre-fitted with a master cone (size, 30; taper, 0.04) (Dentsply Maillefer, Ballaigues, Switzerland) with tug-back sensation at the WL. The transparent replicas were wrapped with opaque tape to prevent the students from directly observing the root canals during filling.

Root canal filling

All students performed root canal filling using two techniques and three sealers under a dental operating microscope. Based on the data of previous studies,[3,11] the sample size was calculated using the G*Power software 3.1.9.6 (Heinrich Heine, Universität Dusseldorf, Germany). The effect sizes of the data for comparison of technique and

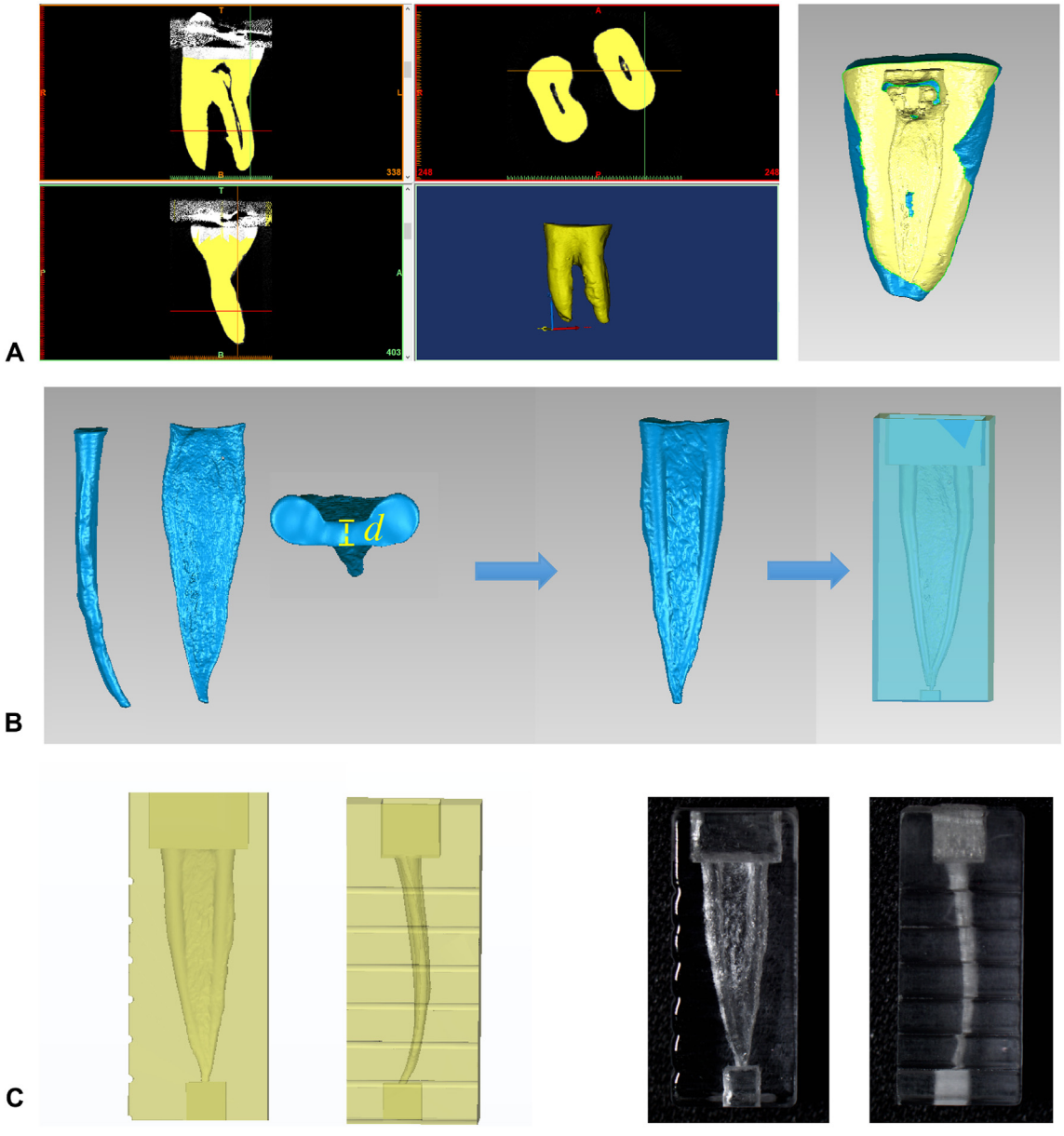

Figure 1 Design and manufacture of the three-dimensional-printed root canal isthmus model. (A) A distal root of the mandibular first molar containing a type IV isthmus was screened from micro-computed tomography data; (B) A three-dimensional model of the root canal system in STL format was generated, printed, and instrumented. The prepared root canal model was scanned using micro-computed tomography and an STL format was generated. (C) Based on the STL data, the root canal model was printed.

sealer were 1.62[3] and 0.85,[11] respectively. Therefore, the data with smaller effect size (0.85) was selected to calculate the sample size, which was determined to be 18 for each group when $\alpha = 0.05$, $1 - \beta = 0.8$, which can yield the actual power of 0.8.[11] Therefore, there were 108 samples divided into the following six groups according to the obturation technique and sealer used.

Group CWC + AH: CWC, AH Plus Jet® (Dentsply DeTrey, Konstanz, Germany); Group CWC + GF: CWC, GuttaFlow2 (Coltene/Whaledent); Group CWC + SP: CWC, iRoot SP (Innovative BioCreamix, Vancouver, BC, Canada); Group SC + AH: SC, AH Plus Jet®; Group SC + GF: SC, GuttaFlow2; and Group SC + SP: SC, iRoot SP.

Before obturation, the morphology of the root canal system and challenges of filling were explained to the students. All students were trained in both filling techniques and each student practiced using two replicas.

CWC: The two root canals were coated with a thin layer of sealer using the selected master gutta-percha cones. Then, the gutta-percha cones with a thin layer of sealer were placed to the WL. A heat carrier (B&L Biotech, Ansansi, Korea) set at 200 °C was inserted into one of the canals to sear and remove the coronal portion of the master cone, retaining only the 4-mm apical gutta-percha cone. During the compaction procedure, heat was applied for 4 s, and pressure was maintained apically for 10 s. After the heat carrier was activated for another 1 s and removed, a cold plugger (B&L Biotech) was used to apically compact the soft gutta-percha. Subsequently, the coronal portion of the canals was backfilled with softened gutta-percha using B&L-Beta (B&L Biotech) at 200 °C to the canal orifice, and vertically condensed with suitable pluggers.

SC: The sealer was first injected into the two root canals using plastic needles. A plastic needle was inserted 2 mm below the root canal orifice and the sealer was injected slowly until the root canal was nearly full.[12] The master gutta-percha cone was coated with a thin layer of sealer and slowly inserted into one of the canals to the WL without a pumping motion. Then, the other root canal was obturated with another master gutta-percha cone. A heat carrier was used to sear the gutta-percha cones at the root canal orifice and the softened gutta-percha cones were vertically condensed with a cold plugger.

Analysis of filling quality

After obturation, the samples were stored at 100% relative humidity and 37 °C for two weeks to allow complete setting of the sealers. All samples were sectioned with a low-speed saw under water cooling at 2, 4, 6, and 8 mm from the apex. Images of the sections were acquired using a stereomicroscope (Olympus SZ61, Olympus, Tokyo, Japan) with 30× magnification. The root canal and void areas were measured using ImageJ software (https://imagej.net/software/fiji/, National Institute of Health, Bethesda, MD, USA) and the percentage of filled area (PFA) was calculated.

Statistical analysis

The Shapiro-Wilk test revealed that the data deviated from a Normal distribution. The data were analyzed using the Mann-Whitney *U* test or Kruskal-Wallis one-way ANOVA with Dunn's tests ($\alpha = 0.05$). All statistical analyses were performed using IBM SPSS Statistics V26 software (IBM SPSS Statistics for Windows, Armonk, NY, USA).

Results

A total of 108 samples and 432 cross sections were analyzed. Representative images of root canal obturations using the two techniques are shown in Fig. 2. Among the 108 samples, only seven samples showed no voids. The PFA, the position and level of the voids following CWC and SC are shown in Table 1.

The CWC group exhibited a higher PFA than the SC group ($P < 0.05$). The root canal system was divided into two areas: apical area (2 mm and 4 mm sections) and coronal area (6 mm and 8 mm sections), for measurement.[13] SC was prone to large voids in the isthmus (Fig. 3A) and large voids were more easily observed in the apical area than in the coronal area ($P < 0.05$) (Fig. 3B).

Regarding the clinical experience of the operators, the PFA was significantly higher in the SPS group than the JPS group or the US group with CWC ($P < 0.05$) (Fig. 4A). The three clinical experience groups showed similar PFAs with SC ($P > 0.05$) (Fig. 4B).

When using CWC, no statistically-significant difference in PFA was observed between the three sealer groups ($P > 0.05$) (Fig. 5A). However, when using SC with iRoot SP, the PFA was higher than with the other two sealers ($P < 0.05$) (Fig. 5B).

Discussion

In this study, the filling of root canals using CWC and SC performed by students with different levels of clinical experience was evaluated. The results showed that the clinical experience of students had no significant effect on isthmus filling using SC, and that the quality of isthmus filling was influenced by the filling technique itself and the sealers used. Therefore, the null hypotheses were rejected.

This study found that void-free obturation was difficult to achieve for isthmus filling regardless of the technique used. Comparing the two filling techniques, the CWC was superior to SC in terms of PFA. This result is consistent with the results obtained in other studies for band-shaped isthmuses and oval-shaped root canals.[2,14] This may be because the pressure was not enough with SC and it was impossible to match the gutta-percha cone to the prepared root canal perfectly to generate enough hydraulic pressure. Voids were observed in the isthmuses as well as the main canals, not only within the filling mass, but also along the gutta-percha—sealer interface and the resin—filling material interface. More voids were found in the apical region than in the coronal region, indicating that filling of the apical canal is still the most difficult aspect of root canal obturation.[9] Even with CWC, it was still difficult to melt the gutta-percha cone at the apical canal sufficiently. Therefore, whether CWC or SC was used, filling of the apical region still relied more on sealers. Consequently, it is necessary to improve the filling effect of the sealer in the apical canal.

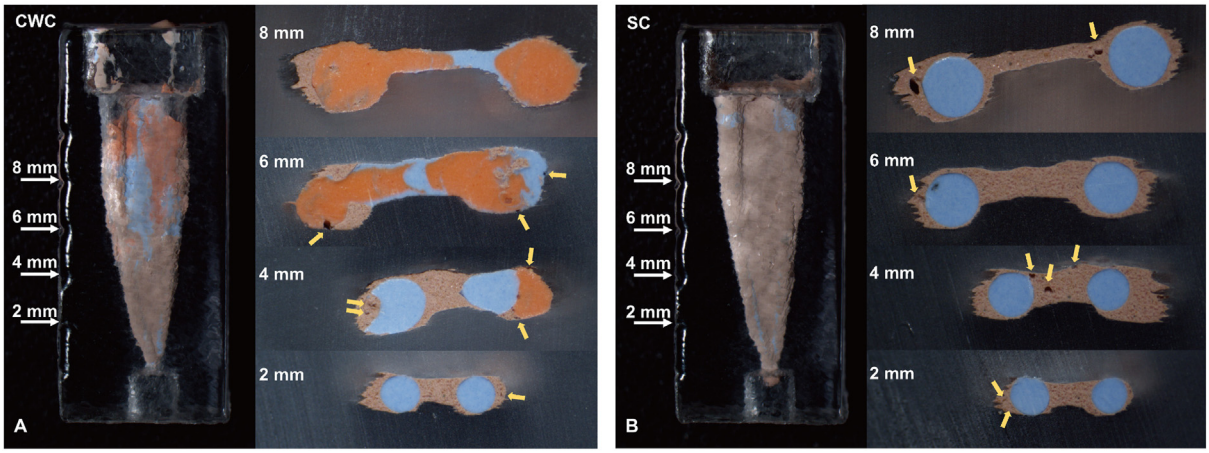

Figure 2 Typical images of root canal obturation using continuous wave of condensation (CWC) (A) and single-cone obturation (SC) (B).

Table 1 Percentage of filling areas (PFA), the number (percentage) of sections with voids among total 432 cross sections, and the position and level of voids, using continuous wave of condensation (CWC) and single-cone obturation (SC).

Technique	Median (Q1, Q3) %	Position of voids n (%)				Level of voids n (%)			
		None	Isthmus	Main canal	Both	2 mm	4 mm	6 mm	8 mm
CWC	99.62 (97.94, 100)	64 (29.63)	24 (11.11)	73 (33.80)	55 (25.46)	35 (16.20)	46 (21.30)	40 (18.52)	31 (14.35)
SC	99.24 (94.03, 100)	62 (28.70)	19 (8.80)	51 (23.61)	84 (38.89)	32 (14.81)	43 (19.91)	41 (18.98)	39 (18.06)

Q1, the first quartile; Q3, the third quartile.

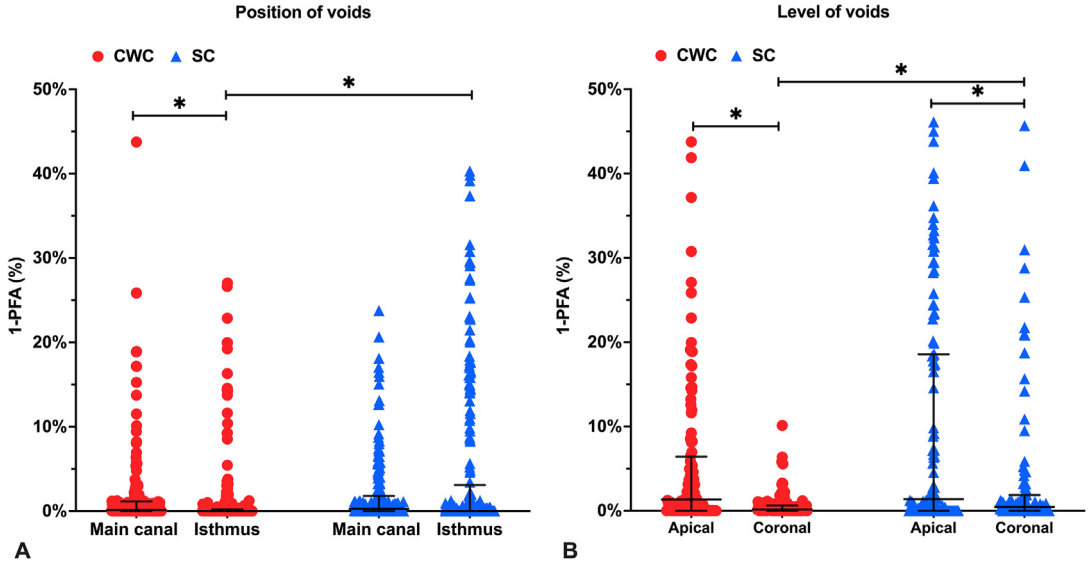

Figure 3 Analysis of the position and level of voids. (A) Scatter plot of voids in the isthmus and the main canal using the two techniques. (B) Scatter plot of voids in apical and coronal areas using the two techniques. PFA, percentage of filled area. CWC, continuous wave of condensation. SC, single-cone obturation. *$P < 0.05$.

Differences of clinical experience among operator groups also led to differential results for isthmus filling with the different techniques. CWC requires special heating and pressurizing equipment. Pressure, temperature, and heating-time are important factors that may influence the filling quality.[15,16] Meanwhile, it is important to consider the risk of thermal damage and root microcracks caused by excessive heating or pressure.[17,18] Therefore, CWC is commonly perceived as being technique-sensitive, difficult for beginners, and requiring operative training.[19] In contrast, SC does not require special equipment, and it is low-cost, easy to perform and is considered less technique-

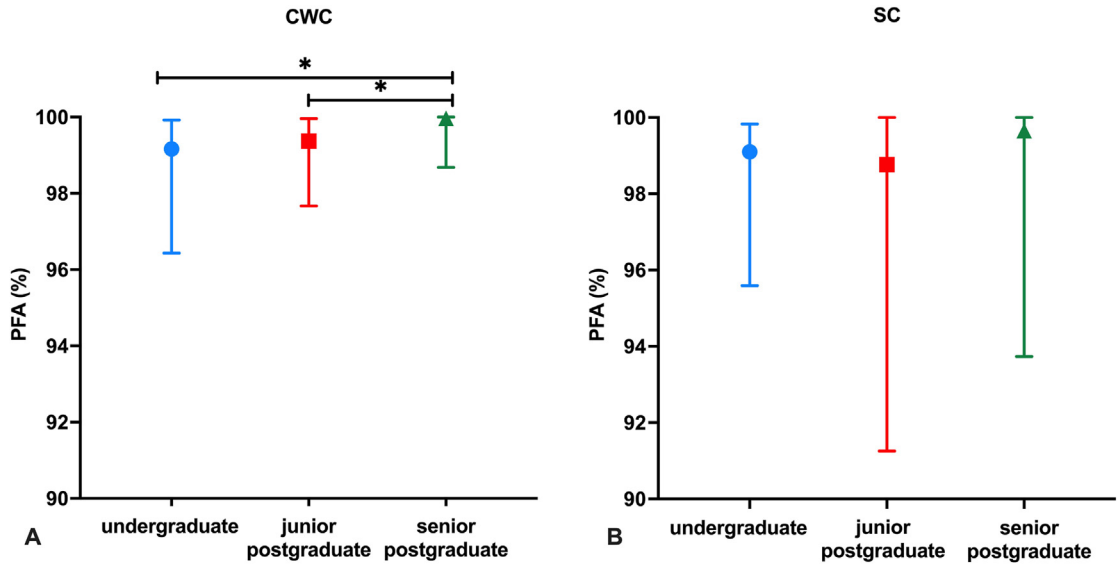

Figure 4 Analysis of percentage of filled area (PFA) in the different experience groups using continuous wave of condensation (CWC) (A) or single-cone obturation (SC) (B). *$P < 0.05$.

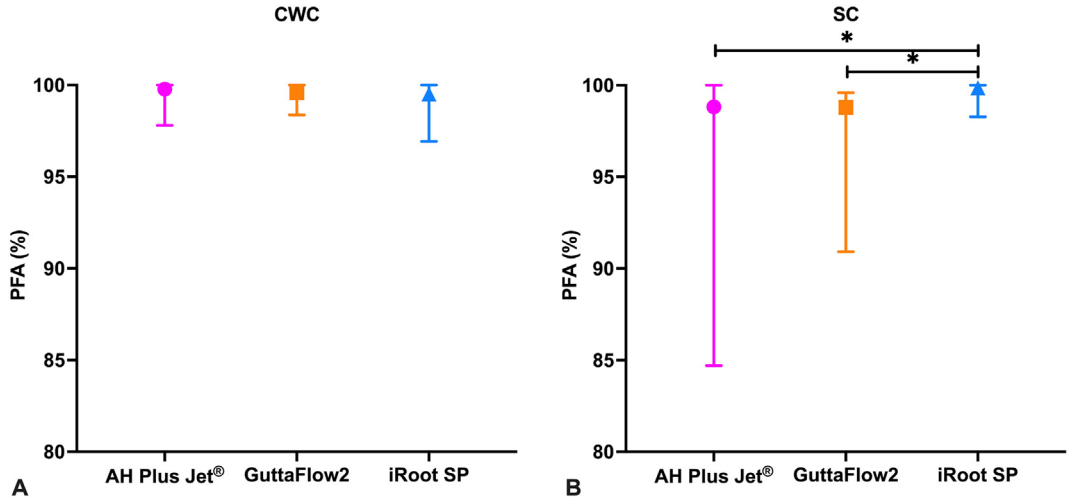

Figure 5 Analysis of percentage of filled area (PFA) in different sealer groups using continuous wave of condensation (CWC) (A) or single-cone obturation (SC) (B). *$P < 0.05$.

sensitive.[20,21] An international survey showed that general dental practitioners are more willing than endodontic practitioners to use SC because of its simplified clinical procedure.[22] In this study, compared with CWC, the SPS group exhibited a higher PFA than the JPS group or the US group, which suggested that proficiency in CWC improved with clinical practice. In the JPS group and the US group, the period over which students had used CWC was approximately half a year or less. This suggested that students should receive more training in order to master the way to use CWC to fill isthmuses. However, clinical experience did not affect the filling quality of the isthmus with SC. It should be noted that no students had been trained in SC, but the median PFA was up to 99.24%, indicating that SC is simple and easy to learn. In addition, a large interquartile range was associated with SC. This was considered to reflect the variation in performance among novices,[19] but could also be inherent in filling techniques, independent of clinical experience.[23] Besides, SC uses one gutta-percha cone and relies more on sealers than CWC. In previous studies, different methods were used to introduce sealers into canals during SC, including using a gutta-percha cone,[24] injection,[2] or Lentulo spirals,[25] and there was also no specification for the amount of sealer. The operative details of the SC technique, which vary among individual operators, may affect the filling quality. Therefore, specific training for SC is necessary to improve the consistency of filling quality. In this study, an injection method recommended by manufacturers of the sealers was adopted to inject sealers into root canals. The injection needle was inserted into the coronal 1/3 of the root canal based on the recommendations to reduce the risk of overfilling.[12]

In this study, three typical sealers were selected, representing three different materials. AH Plus Jet® is an epoxy resin-based root canal sealer, which has been widely used for comparison because of its good physicochemical features and adapt-ability to the root canal walls.[26,27] The calcium silicate-based sealer iRoot SP has attracted considerable attentions due to its good biocompatibility, bioactivity, sealing ability, osteoconductive effects and ability to chemically bond to root canal dentin.[28,29] GuttaFlow2 is a silicone-based root canal sealer that combines sealer and gutta-percha in powder form with a particle size of less than 30 μm, which has been shown to be more biocompatible than AH Plus Jet® and less toxic to human gingival fibroblasts cells than AH Plus Jet®.[30] A significant difference was also observed between the different sealer subgroups with SC. The results in this study showed that iRoot SP resulted in a higher PFA than AH Plus Jet® or GuttaFlow2. Other studies previously confirmed that bioceramic sealers had lower or similar percentages of voids compared to AH Plus or silicon-based sealers.[31—33] On the one hand, this may be due to the good fluidity of iRoot SP.[34] On the other hand, compared with in freshly extracted teeth, the setting time of iRoot SP may prolong in the hydrophobic resinous canal model, whereas the setting time of resin-based sealers is not affected by media.[35] This may yield limited observation and need further research in freshly extracted teeth.

In addition, some other limitations in this study could not be overlooked. An important limitation of the present study was the small sample size of students. The selected students in this study are those receiving specialized training in endodontics, special training and consistency evaluation before experiment. These students are representative of students with different levels of clinical experience. But due to the limited number performed by students, it needs further research increasing the sample size to verification. The resin inner wall of the root canal could not completely simulate the clinical reality. When using CWC, the students needed to be instructed to avoid heating the resin root canal wall directly with the heat carrier for a long time, and no visible deformation of the root canal model was detected after obturation. Another limitation was that the assessment in the two-dimensional plane could not give 3D volumetric information. Micro-CT has been shown to be superior in this sense,[2,9,36] but micro-CT image artifacts within the sealers can affect the assessment of voids as sealers are radiopaque.[37,38] Sectioning is a simple method for easy implementation without the need of expensive equipment.

In conclusion, based on this limited study, CWC was technique-sensitive and required clinical training for students to master the technique and accommodate complex isthmuses. For SC, clinical experience did not improve the quality of isthmus filling without additional training. In clinical training, SC also required systematic training and specification of details. CWC was superior to SC for type IV isthmuses. When SC was used, better filling could be obtained with the use of bioceramic sealers.

Declaration of competing interest

The authors declare that they have no conflicts of interest with the contents of this article.

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