Pre-Clinical Research Report

Journal of INTERNATIONAL MEDICAL RESEARCH

Journal of International Medical Research
2019, Vol. 47(1) 470–480

DOI: 10.1177/0300060518814604
journals.sagepub.com/home/imr
SAGE

Effect of obturation technique with immediate and delayed post space preparation on apical voids and bond strength of apical gutta-percha

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Abstract

Objective: The purpose of this study was to evaluate the effect of immediate and delayed post space preparation on the sealing ability of two root canal obturation techniques by using micro-computed tomography imaging and a push-out test.

Methods: The root canals of 40 human maxillary premolar teeth were instrumented and divided into four groups: (A) single cone (SC) followed by immediate post space preparation, (B) continuous wave of condensation (CWC) followed by immediate post space preparation, (C) SC followed by delayed post space preparation, and (D) CWC followed by delayed post space preparation. Micro-CT scans were performed for volumetric analysis of voids and filling materials in the apical 4-mm portion. A push-out test was performed, and failure modes (adhesive, cohesive, or mixed) were assessed. Data were analyzed using the Kruskal-Wallis test and one-way analysis of variance.

Results: No significant differences were observed among the four groups in terms of the percentage volume of voids of the apical 4 mm or the bond strength of apical gutta-percha.

Conclusions: The percentage volume of voids and bond strength of apical gutta-percha were similar and were not significantly influenced by the timing of post space preparation or the obturation technique.

Keywords

Post space preparation, obturation technique, apical void, bond strength, micro-computed tomography, push-out test, failure mode

Date received: 11 September 2018; accepted: 31 October 2018

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Introduction

Successful root canal treatment depends on chemo-mechanical cleaning, shaping, and obturation of root canals. Filling of root canals with good sealing ability is essential to prevent re-infection or recolonization with bacteria.[1] Calcium silicate-based sealer has been proposed as an endodontic filling material because of its excellent biocompatibility, bioactivity, and osteoconductivity.[2] With the emergence of Ni-Ti matched taper gutta-percha cones and improvements in root canal sealer properties, the single cone (*SC*) obturation technique has gradually emerged and is considered less operator-dependent and less damaging to the dentin wall, compared with lateral compaction and continuous wave of condensation (*CWC*).[3–5]

After complete endodontic management, radicular posts are generally required to assist in restoring full function for teeth with insufficient coronal tooth structure.[6] Because creation of the post space results in a weaker barrier to coronal leakage, maintaining the integrity of remaining filling material is critical.[4] The techniques and instruments used for gutta-percha removal and the remaining amount of root canal filling, as well as the obturation techniques, type of sealer, and timing of post space preparation, may also result in leakage.[7] Therefore, it is necessary to evaluate the sealing ability of the obturation material after preparing the post space.[8]

Timing of post space preparation can be classified as immediate or delayed. Immediate post preparation has considerable advantages regarding sealing ability, compared with the traditional delayed post preparation.[8–10] Immediate post space preparation can be completed using the same aseptic conditions, without the need to re-open the root canal (as in delayed post preparation). Simultaneously, the remaining gutta-percha can be assessed and improved if necessary. In addition, immediate post space preparation can shorten the course of treatment. Finally, the familiarity of the operator with the root canal system minimizes the risk of perforation or stripping.[8–10] However, no consensus exists regarding the correct time to perform post space preparation.

The purpose of this study was to evaluate the apical sealing ability of immediate and delayed post space preparations using the *CWC* and *SC* techniques with calcium silicate-based sealers.

Materials and methods

Specimen preparation

After obtaining informed consent from patients, forty permanent human maxillary premolar teeth that had been extracted for orthodontic treatment in Guanghua School of Stomatology, Affiliated Stomatological Hospital, Sun Yat-sen University were stored at room temperature in saline solution to keep the surface wet. The present study was approved by the Research Ethics Committee of the same university. Teeth were selected that exhibited double root canals, including two roots and one root with two separate apical foramina that were devoid of caries, fractures, resorption, or defects. The teeth were cleaned carefully with curettes to remove any remnant of soft tissue, and then were stored in saline solution. Teeth were decoronated at the cementoenamel junction. A No. 10 K file (Dentsply Maillefer, Ballaigues, Switzerland) was inserted in the root canal through the apical foramen until the tip of the instrument became visible at the apical foramen; this length was recorded for each root. The working length (WL) was determined by subtracting 0.5 mm from this length, and the root canals were cleaned and shaped to a size 30.04 taper using Ni-Ti rotary instruments (M3 Rotary

System, United Dental, Shanghai, China), in accordance with the manufacturer's recommendations. The canals were rinsed with 2.5 mL of 1% sodium hypochlorite (NaOCl) and saline solution between instrumentations. After preparation, 5 mL of 17% ethylenediaminetetraacetic acid solution was used to irrigate the root canals for 1 minute to remove the smear layer, followed by 5 mL of 1% sodium hypochlorite and saline solution. The root canals were dried with absorbent paper points and filled with calcium hydroxide (CH) (Ivoclar Vivadent, Schaan, Principality of Liechtenstein) for a 2-week sterilization; then, the teeth were stored at 37°C and 100% humidity. After sterilization, a No. 10 K file was inserted through the apical foramen of each canal to ensure patency and to re-measure the WL. Saline solution was used to rinse the CH, and the root canals were dried with absorbent paper points.

Experimental procedure

Depending on the obturation technique and the timing of post space preparation, the teeth were randomly divided into four experimental groups (n=10).

In group A (*SC* followed by immediate post space preparation, *SC-I*), the specimens were obturated with a tapered gutta-percha cone size 30.04 (3M ESPE, Seefeld, Germany) and iRoot SP root canal sealer (Innovative BioCeramix Inc., Vancouver, BC, Canada). The gutta-percha cone was introduced in the root canal until the WL was reached, and then checked for resistance. iRoot SP sealer was injected into the inner canal, and the gutta-percha was coated with sealer and inserted. The teeth were radiographically imaged to confirm the quality of obturation. The coronal root filling material of the palatal root canal was removed using the heat source of the obturation unit (SybronEndo, Kerr Endodontics, Orange, CA, USA), leaving 4 mm of filling material in the apical portion. Post-fixation spaces were standardized with the post space preparation system (3M ESPE), corresponding to a medium-sized fiber post (3M ESPE). Irrigation was performed with 5 mL of 1% sodium hypochlorite solution, followed by a final rinse with 5 mL of saline solution. Finally, each root canal was dried using absorbent paper points. Dentin adhesion was accomplished using Scotchbond™ Universal Adhesive (3M ESPE). In accordance with the manufacturer's instructions, the post was cleaned with alcohol, and Scotchbond™ Universal Adhesive was applied to the post space wall and the surface of the post. RelyX™ Ultimate Adhesive Resin Cement (3M ESPE) was injected into the post space, and the post (red) was inserted for 6 min for polymerization.

In group B (*CWC* followed by immediate post space preparation, *CWC-I*), the appropriate plugger tip of the obturation unit was selected for each root canal. iRoot SP sealer was injected into the inner canal, and the gutta-percha was coated with sealer and then obturated. The heated plugger was pushed through the gutta-percha point slowly, leaving 4 mm of gutta-percha in the apical portion. The remaining buccal canal was backfilled with thermo-plasticized gutta-percha, and the teeth were then radiographically imaged to confirm the quality of obturation. Post space preparation was performed as in group A.

In group C (*SC* followed by delayed post space preparation, *SC-D*), the obturation procedure was identical to that of group A, except for the time allowed for post space preparation. The teeth were stored at 37°C and 100% humidity for 1 week to allow the sealer to set.

In group D (*CWC* followed by delayed post space preparation, *CWC-D*), the obturation procedure was identical to that of group B, and all root canals were backfilled with thermo-plasticized gutta-percha. The procedure and time allowed for post space preparation were identical to those of group C.

After completing all experimental procedures, superfluous posts were sectioned with a slow-speed diamond saw.

Micro-CT analysis

Specimens were scanned by micro-CT imaging after all procedures were completed, to provide volumetric analysis of the filling materials and voids in the apical 4-mm portions of all specimens. Images were obtained using a micro-CT scanner (microCT uCT50, Scanco Medical AG, Basserdorf, Switzerland). The scanning parameters were 8 W, 70 kV, 114 μA, 360° rotation, and a pixel size of 13.73 µm. The filter comprised 0.5-mm-thick aluminum. Mimics Research software (version 19.0, Materialise, Leuven, Belgium) was used to reconstruct and evaluate the samples, yielding 1000–1200 slices per specimen. The original grayscale images were processed to visualize and quantify the root canal, filling material (gutta-percha and sealer), and voids in the apical 4-mm portion of each specimen. Grayscale thresholds were defined to separate root dentin from filling material and voids, and the filling material threshold values were used to qualitatively evaluate the root canal filling volume. The root canal volume was the region of interest comprising the root canal filling and the voids, and was selected for each slice (Figure 1). All images were examined by two evaluators who were blinded to group identity. The volume of voids ($Voids_{Vol}$) was calculated by subtracting the filling material volume ($Filling_{Vol}$) from the root canal volume ($Canal_{Vol}$):

$$Voids_{Vol} = Canal_{Vol} – Filling_{Vol}$$

The percentage volume of the voids (% $Voids_{Vol}$) was calculated using the following formula:

$$\%Voids_{Vol} = Voids_{Vol} \times (100/Canal_{Vol}.$$

Push-out test

The specimens were sectioned perpendicularly to the long axis of the root with a precision low-speed saw (Accutom-50; Struers Ltd., Cleveland, OH, USA) under water cooling. Sequential cuts were 1-mm thick, in an apical to cervical direction. The slices including gutta-percha were collected, and the first and last slices were discarded, resulting in approximately two slices per specimen (Figure 2a). Images of both sides (cervical and apical) of the slices were captured with an optical microscope (Leica Microsystems Ltd., Wetzlar, Germany) at ×20 magnification. ImageJ software (National Institutes of Health, Bethesda, MD, USA; http://imagej.nih.gov/ij/) was used to measure the gutta-percha diameters of both sides (Figure 2b). Thicknesses were measured with a digital micrometer (Vernier Calliper; AIRAJ, Shandong, China), followed by the push-out test. A universal testing machine (Instron Co. Ltd., Norwood, MA, USA) was applied to test the bond strength of the gutta-percha. A cylindrical plunger with a diameter of 0.3 mm was applied in the apical-coronal direction at a speed of 0. 5 mm/minute loading until the filling material was dislodged from the slice. Load at failure was recorded in N. The bond strength values were calculated using the following formula: (MPa) = (N)/ bonded surface area (S). S (in mm^2) was calculated using the following formula:

$$S = \pi(R + r)\left[\left(h^2 + (R - r)\right)^2\right]^{0.5},$$

where R is the radius of the coronal gutta-percha, r is the radius of the apical portion, and h is the thickness of the section.

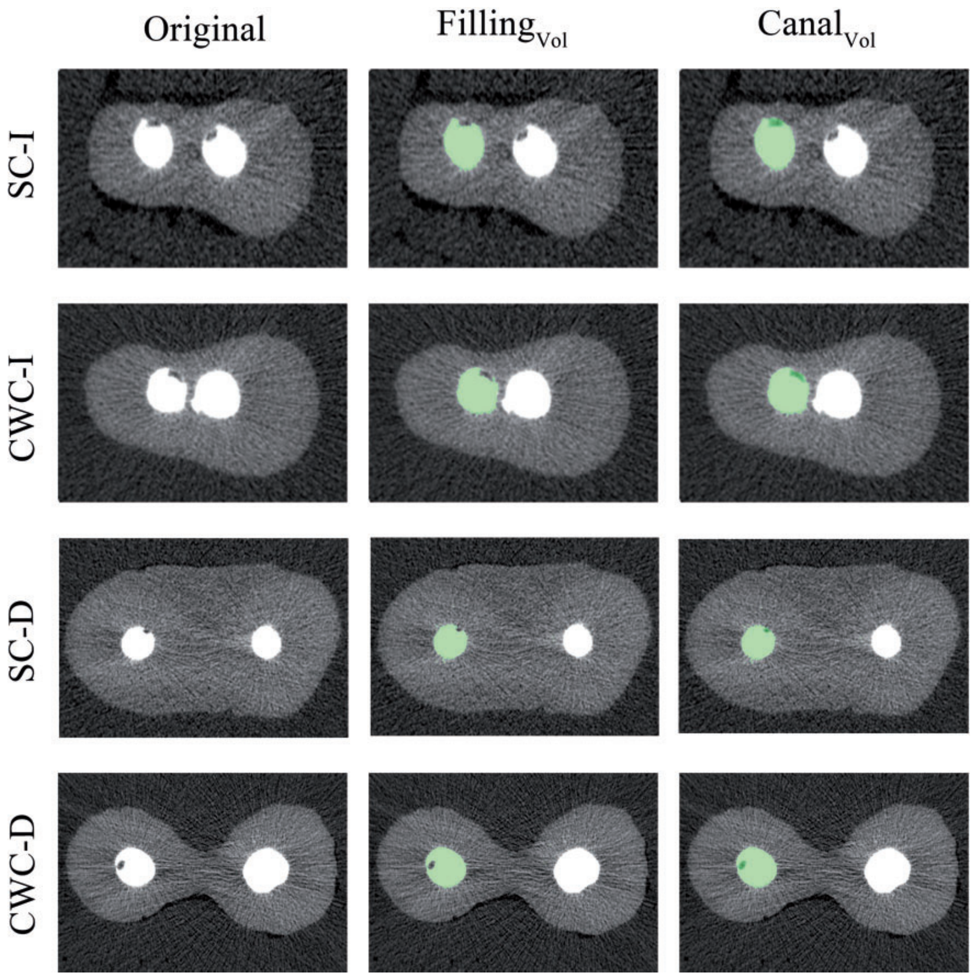

Figure 1. Representative and consecutive micro-CT cross sections from the apical 4 mm after post space preparation, which show the presence of voids (black spots within filling materials) and filling materials (in white) on the original grayscale images. The Filling$_{Vol}$ (in green) was calculated, and the Canal$_{Vol}$ includes the Voids$_{Vol}$ and Filling$_{Vol}$. SC-I, single cone followed by immediate post space preparation; CWC-I, continuous wave of condensation followed by immediate post space preparation; SC-D, single cone followed by delayed post space preparation; CWC-D, continuous wave of condensation followed by delayed post space preparation.

For analysis of failure modes, all slices were evaluated under an optical microscope at ×60 magnification. In accordance with the method of Pereira et al.,[11] failures were classified as follows: adhesive (if the filling material was separated from the dentin); cohesive (if detachment appeared between the sealer and gutta-percha); and mixed (a mixture of adhesive and cohesive modes) (Figure 3).

Statistical analysis

Data were analyzed using SPSS Statistics for Windows software version 20.0 (IBM Corp., Armonk, NY, USA). The mean %Voids$_{Vol}$

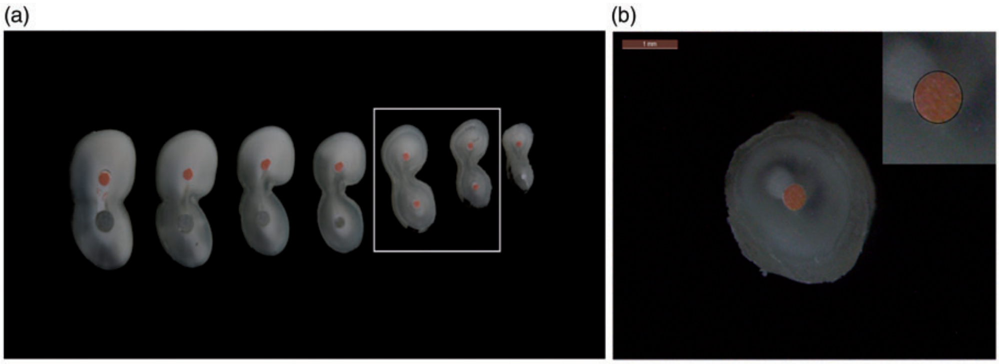

Figure 2. (a, b) Images of the slices and apical portion marked for calculation of the radius of the gutta-percha.

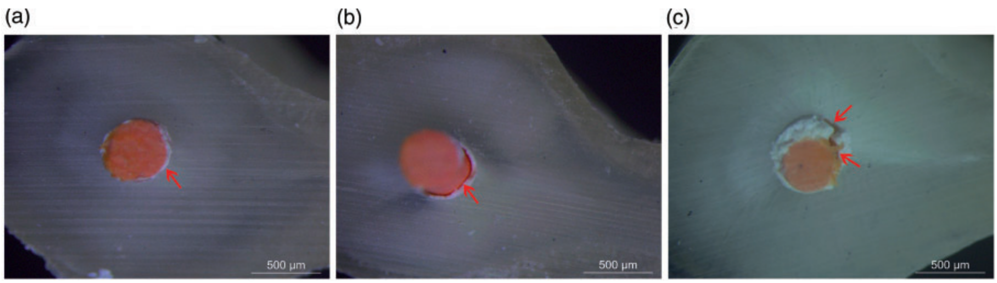

Figure 3. Failure modes characterized by fracture location (arrows), evaluated by optical microscopy. (a) Adhesive, (b) cohesive, and (c) mixed failures observed in the apical one-third of the canals. Scale bar = 500 µm.

did not follow a normal distribution, as determined by the Shapiro-Wilk test; therefore, non-parametric tests were used. Overall comparisons among the different groups were analyzed using the Kruskal-Wallis test at a significance level of 0.05. Bond strength followed a normal distribution and was evaluated by one-way analysis of variance (ANOVA). A *p*-value of less than 0.05 was considered statistically significant.

Results

Figure 4 shows the median (interquartile range) %$\text{Voids}_{\text{Vol}}$ of the apical 4-mm portion of each group ($P > 0.05$). No significant differences were observed among the four groups. Push-out bond strength values are shown in Figure 5, and no significant differences were found among the four groups, similar to the results of %$\text{Voids}_{\text{Vol}}$ analysis.

The failure modes of the specimens are shown in Table 1. Cohesive failure between the sealer and gutta-percha occurred more frequently than mixed failure or adhesive failure.

Discussion

Suitable root canal obturation without voids and proper adhesion of the root canal filling are associated with more successful outcomes.[12,13] The present study was designed to evaluate the quality of

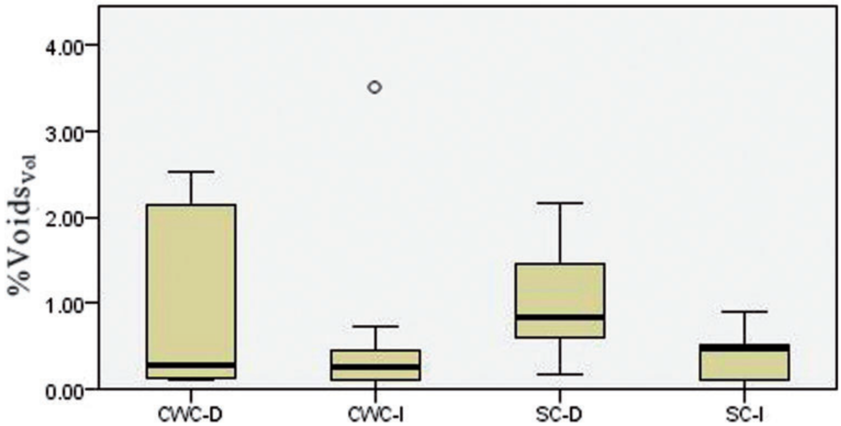

Figure 4. Box and whisker plots of %Voids$_{Vol}$ in all experimental groups. The upper and lower ends of the whisker lines indicate the highest and lowest loads at the %Voids$_{Vol}$, respectively. The upper and lower ends of the boxes represent the 75th and 25th percentiles, respectively. The horizontal lines indicate the median, and the circle represents an excessive value. SC-I, single cone followed by immediate post space preparation; CWC-I, continuous wave of condensation followed by immediate post space preparation; SC-D, single cone followed by delayed post space preparation; CWC-D, continuous wave of condensation followed by delayed post space preparation.

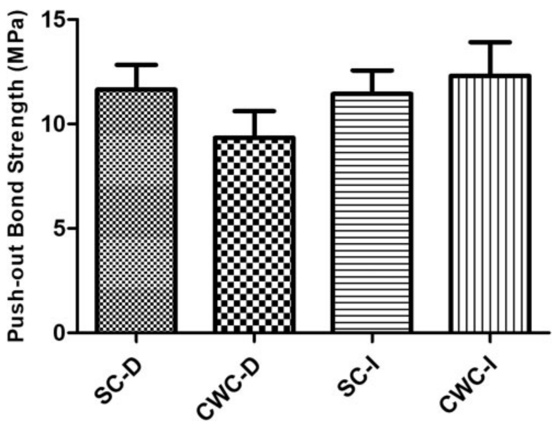

Figure 5. Bond strength (MPa, mean ± standard deviation) for each cross-sectional root canal of the apical portion in each group. SC-I, single cone followed by immediate post space preparation; CWC-I, continuous wave of condensation followed by immediate post space preparation; SC-D, single cone followed by delayed post space preparation; CWC-D, continuous wave of condensation followed by delayed post space preparation.

remaining apical obturation, relative to the %Voids$_{Vol}$ and bond strength of the gutta-percha, after immediate and delayed post space preparation in maxillary premolars. These teeth were chosen because of their complex anatomy, which made disinfection and obturation difficult.[14,15] Most previous studies have comprised evaluation of single root canals,[8,16,17] and no data have yet been reported regarding the quality of complex

Table 1. Failure modes (%) observed for each cross section of the apical portion in each group.

	SC-I	*CWC-I*	*SC-D*	*CWC-D*
Adhesive	18.18	13.64	8.70	9.09
Cohesive	72.73	72.72	78.26	86.36
Mixed	9.09	13.64	13.04	4.55

SC-I, single cone followed by immediate post space preparation; CWC-I, continuous wave of condensation followed by immediate post space preparation; SC-D, single cone followed by delayed post space preparation; CWC-D, continuous wave of condensation followed by delayed post space preparation.

canals. In addition, CH was used as intracanal medication to disinfect the complex root canal systems. Some authors have reported that CH influenced the filling material adaptation and dentin bond strength; however, CH has been widely used as an intracanal medication in endodontic treatment.[18] Chemo-mechanical preparation with intracanal medication was primarily responsible for improving the reduction of bacterial loading.[19] Thus, CH was applied to simulate the clinical protocols.

To the best of our knowledge, the *CWC* technique is commonly used because it can provide better filling of canal irregularities.[20] Some authors have shown a greater incidence of failure with the *SC* technique because obturation of irregularities in the root canal system is more difficult.[21,22] Nevertheless, Somma et al.[23] studied the percentages of filling and void distributions of *CWC* and *SC* in regular canals and found no significant differences. Additionally, although the *CWC* technique showed better filling than the *SC* technique for irregular canals in the cervical region, the filling was similar in the apical and middle regions.[24] Therefore, removal of the coronal root filling material during post space preparation could resolve the problem of poor *SC* filling of the cervical one-third of irregular canals. In the present study, there were no significant differences between the *CWC* and *SC* groups in the % $\text{Voids}_{\text{Vol}}$ of the apical portion. Similar to our findings, Özkurt-Kayahan et al.[16] showed that the *SC* and calamus techniques produced similar degrees of apical microleakage after immediate post space preparation. In contrast to our results, Schafer et al.[20] demonstrated that delayed post space preparation negatively affected the obturation quality of teeth obturated with the *SC* technique, whereas it had no significant influence on the obturation quality of teeth obturated with the *CWC* technique. These differences might be due to the use of Peeso reamers to remove the coronal root material, as well as use of the *SC* technique without compaction for the remaining filling. Micro-CT was employed to measure the voids by three-dimensional analysis, which has become increasingly used to examine obturation quality because it is an effective, noninvasive, and nondestructive method.[25]

Post space preparation can be performed by several techniques; these include chemical, thermal, or mechanical removal of the root filling material.[26] In this study, the post space was prepared mechanically with a post drill after using the heat source of the obturation unit to remove the coronal root filling material. Thermal removal of material has additional benefits in terms of efficiency and safety. The hot plugger method was used to help avoid deviation from the canal anatomy, especially during immediate post space preparation, because the operator was familiar with the root canal system of the teeth. Furthermore, preparing the post space by this method requires less time.[8] Nevertheless, disagreement persists regarding the ideal time for post space preparation. Dalat and Spångberg indicated that the root filling might be dislodged during mechanical post space preparation when sealer setting has not been achieved.[27] In contrast, no gutta-percha cone was present for dislodging during immediate post space preparation in the present study. In addition, there were no significant differences among the four groups in terms of $\%Voids_{Vol}$. Notably, the use of the thermal unit and compaction component to maintain the integrity of the apical filling material during post space preparation may explain the similar voids in the apical portion.[28]

In the present study, sodium hypochlorite was used for the irrigation of post space, in accordance with the manufacturer's instructions for RelyX™ Ultimate Adhesive Resin Cement. However, Garcia et al.[29] showed that sodium hypochlorite negatively influenced the bond strength between self-adhesive resin cement and root dentin. Conversely, some studies have reported an increase in bond strength after treatment with sodium hypochlorite.[30] Moreover, Kul et al.[31] showed that there was no significant difference between sodium hypochlorite and distilled water in the bond strength of fiber posts attached with self-adhesive resin cement. These diverse effects of sodium hypochlorite on bond strength could occur because different products have distinct performance characteristics, and because processing is not identical; therefore, the influence of sodium hypochlorite is not identical among conditions.

Based on the lack of significant differences in $\%Voids_{Vol}$ among the four groups, we subsequently performed a push-out test. Because adhesion to root canal dentin is a desirable property for obturation, it is essential in both static and dynamic situations. Good adhesion eliminates microleakage that can allow fluids to permeate among the fillings and dentin, and maintains steadiness of the fillings during subsequent procedures, such as post space preparation.[13] No significant differences were found in the results of the push-out test of bond strength of the apical gutta-percha. This result may have occurred because of the sealer's excellent properties. Calcium silicate-based sealers require water to form calcium silicate hydrate and CH, thereby achieving an appropriate degree of setting.[32] The sealing efficacy of this sealer was superior to that of other materials with reported bioactive properties.[4] A bioactive material should have the ability to provoke a specific biological response at the interface of the material with its surroundings, resulting in a stable bond between the material and dentin.[4,33,34] Adherence of the sealer to the canal walls can preserve the stability of the sealer-dentin interface during mechanical stresses caused by tooth flexure, operative procedures, or subsequent preparation of a post space;[35,36] this could also explain the higher rate of cohesive failures, compared with rates of adhesive and mixed failures. Furthermore, this adherence may have been responsible for the difficulty encountered in removing coronal root filling material during the process of delayed post space preparation, as the sealer had thus set completely.

Measurement of the $\%Voids_{Vol}$ and adhesive strength can be used to assess the quality of obturation; however, the relationships between these measurements and treatment failure remain uncertain. According to the present results, the *CWC* and *SC* techniques with calcium silicate-based sealers, followed by either immediate or delayed post space preparation, have a similar effect on obturation quality. Nevertheless, clinical research remains necessary to confirm this hypothesis.

Declaration of conflicting interest

The authors declare that there is no conflict of interest.

Funding

This study was financially supported by the Natural Science Foundation of Guangdong Province (project No. 2017A030313713).

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