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Original Article

Presence and distribution of voids after using the single cone obturation technique with different sealer placement methods in canals with an isthmus

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Abstract *Background/purpose:* The obturation of canals with irregular structures is still a challenge for single cone obturation technique (SC). The purpose of this study was to evaluate the presence and distribution of voids using SC with different sealer placement methods in the canal with a simulated band-shaped isthmus.
Materials and methods: 3D-printed root canal models with band-shaped isthmuses were randomly divided into four groups according to different obturation methods. Group 1: sealer placement by single cone passively (SCP); Group 2: bi-directional spiral-supported sealer placement (BS); Group 3: ultrasound-supported sealer placement (U). Group 4: vertical compaction obturation (VC). In each group, 10 of 14 models were sliced and the remaining four were scanned by micro-CT. The percentage area of voids (PAV) and the percentage volume of voids (PVV) of fillings were calculated.
Results: At all slice levels, using BS and U to support sealer placement reduced voids with an average PAV of 21%, and in the VC and SCP groups were 33% and 45% respectively. Based on the

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micro-CT scans, nearly half of the porosity decreased by the BS and ultrasound in the isthmus with PVV of 25% and 29% respectively, compared with 46% in the SCP group. However, in the main canal, when the PVV was 22% in the SCP group, the porosity decreased to 14% in the U group and 18% in the BS group.
Conclusion: Bi-directional spiral or ultrasound-supported sealer placement can improve the performance of single cone obturation in canals with an isthmus.

Introduction

Root canal therapy is an important method to eliminate the infection from the root canal and prevent the re-infection, which depended on the triad of debridement, thorough disinfection, and successful obturation.[1] The single cone obturation technique (SC), proposed in 1961 by Marshall & Massler,[2] exploits the natural space in the root canal to fill gutta-percha cones and sealers without squeezing and is less sensitive to variations in technique or operator ability.[3] However, previous studies have shown that the quality of the SC technique is compromised compared with that of the lateral compaction (LC) or vertical compaction obturation techniques, which could be attributed to the limitations of the traditional root canal sealer materials, such as volume shrinkage, dissolution, and cytotoxicity.[4,5]

With the advance of calcium silicate-based sealers and the emergence of new kinds of canal sealers, such as bioceramic sealers and multicomponent hybrid sealers, they have provided better biocompatibility, flow, and dimensional stability for obturation,[6] the single-cone obturation technique achieved optimal quality compared with the continuous wave and LC in single and straight canals.[3,7] A 90.0% success rate was also reported in a 30-month retrospective analysis of 377 teeth with periapical disease.[8]

However, it is still a challenge for the single-cone obturation technique to fill canals with irregular structures, such as the isthmus, c-shaped canals, and heavily curved root canals.[9–13] Several methods have been proposed to improve the quality of SC in irregular anatomical structures, such as using K files or ultrasonic activation to decrease the number of voids and increase the penetration of sealers into irregular anatomical structures.[14,15] Few evidence-based studies have been conducted to evaluate and compare the efficiency of different improvement methods in the standardization of experimental techniques and models.

This study aimed to evaluate the presence and distribution of the voids after using single-cone obturation with different sealer placement methods in 3D-printed root canal models with a simulated band-shaped isthmus.

Materials and methods

Specimen preparation

Freshly extracted premolars with Hus & Kim V-type and Yin-type II band-shaped isthmuses based on the cone beam computed tomography data were collected and instrumented with ProTaper Gold nickel-titanium file F3 (30#/0.09) (Dentsply Sirona, Ballaigues, Switzerland). After being scanned by micro-CT and designed by Geomagic Studio software (Raindrop Geomagio Inc., Research Triangle Park, NC, USA), the file of the model was imported into an Objet 30 Pro 3D resin printer with an accuracy of 16 μm (Stratasys Ltd., Rehovot., Israel), and root canal models of the transparent resin material RGD810 (Stratasys Ltd.) were printed. The band-shaped isthmus of the model started from the canal orifice and stopped at 3.04 mm from the apical foramen; the minimum diameter was 0.15 mm, and the maximum diameter was 4.40 mm (Fig. 1).

Fifty-six printed root canal models with band-shaped isthmuses were randomly divided into four groups according to different obturation methods (n = 16). Groups 1–3 were obturated with the single cone technique (SC), and group 4 with vertical compaction obturation technique(VC), a gutta-percha (#30/0.06) was used as the master cone, and 0.5 ml of GuttaFlow 2 (Colténe/Whaledent, Altstätten, Switzerland) was used as the sealer.

Group 1: Sealer placement by single cone passively (SCP): A master cone was fit short of the prepared working length (WL) of 0.5 mm with resistance to displacement. After sealer was injected from the canal orifice to the root middle 1/2 by syringe(30#) and the master cone was inserted slowly into the WL, the coronal portion was removed with a heated plugger (B & L Biotech Inc., Ansan, Korea).

Group 2: Bi-directional spiral-supported sealer placement (BS): After injecting the sealers, a bi-directional spiral (EDS, Hackensack, NJ, USA) was used to introduce sealers at a distance of WL-2mm for 2s with 2000 rpm.

Group 3: Ultrasound-supported sealer placement (U): An ultrasonic tip 15# (Satelec, Merignac Cedex, France) was used to introduce sealers at a distance of WL-2mm for 2s with a power setting of 6 (Staelec).

Group 4 (control group): A master cone was selected and fit short of the prepared length of 0.5 mm, and then the canal was obturated with continuous wave obturation technology.

After the root canal obturation, the overfilling of each model was recorded. The orifice was sealed with 2 mm Ceivitron (Triune Med Tec, Cambridgeshire, UK), and the specimens were stored at 37 °C and 100% relative humidity for 1 week to allow the sealers to become fully cured.

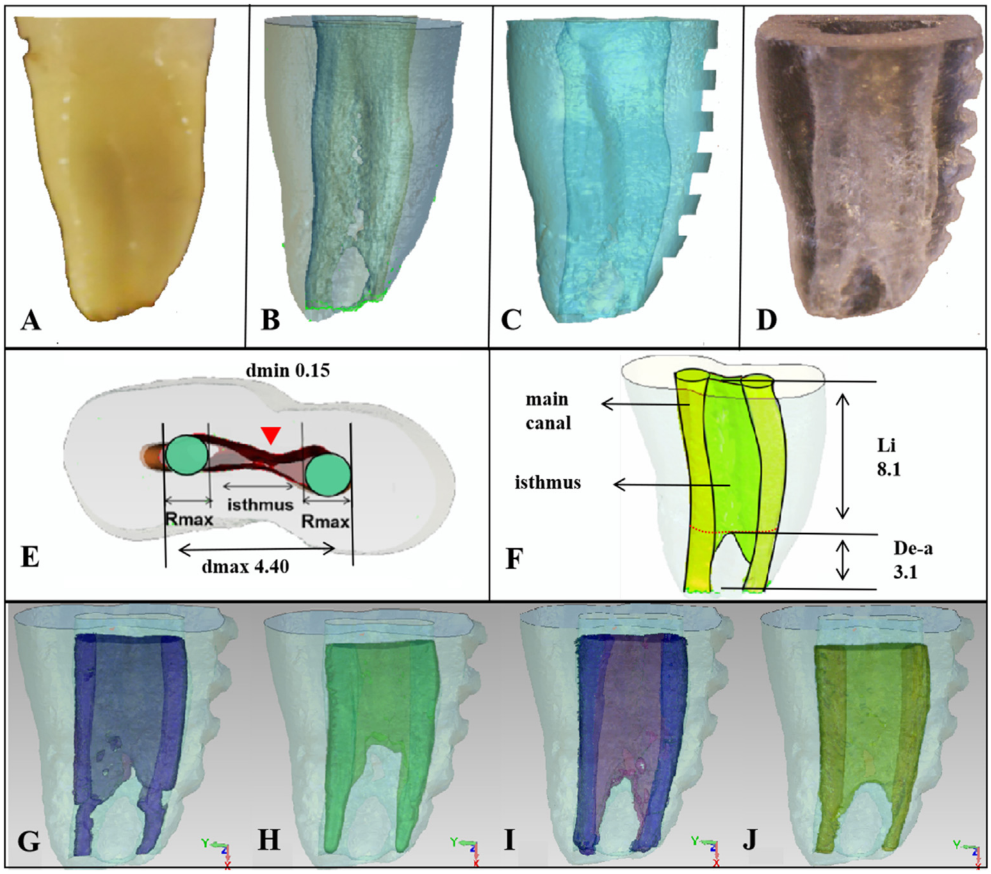

Figure 1 Freshly extracted premolars scanned by micro-CT (A); then, the samples were reconstructed (B) and designed (C), the transparent resin material was printed (D), measurements and verification of usability were performed, the isthmus and main root canal were defined on the axial plane (E), the isthmus and main root canal area were divided (F), and the filling volumes of the VC group (G), SCP group (H), BS group (I) and U group (J) were calculated. dmin: the minor diameter of canals in the cross-section of the isthmus dmax: the maximum major diameter of the same cross-sections. De-a: the distance between the dmin cross-section and apex. Li: isthmus length.

Evaluation of the slices

In each group, 10 of the 14 canal models used 0.35 m thick slices at 2, 4, 6, and 8 mm from the root apex in the direction perpendicular to the long axis of the root using a 200 rpm low-speed blade, and the slices were observed under a stereomicroscope (20 × magnification) (Olympus, Tokyo, Japan) (Fig. 2). ImageJ 2.0 (National Institutes of Health, Bethesda, Md, USA) was used to process and analyze the areas of the root canal filling, the gutta-percha, the sealer, and the percentage area of voids (PAV) was calculated as follows:

$$\text{Percentage area of voids (PAV)} = \frac{\text{canal areas} - \text{filling areas}}{\text{canal areas}} {}^{*}100\%$$

Evaluation of micro-CT

The remaining four models of each group were scanned by Micro-CT (Siemens, Munich, Germany) with a voxel size of 0.18 μm. Mimics software (Materialise NV, Leuven, Belgium) was used to mark and reconstruct the images via the grey threshold segmentation function. The threshold range of the resin roots was −100 to −120, and the threshold of the filling material (gutta-percha and sealer) was 185–205. The voids determined the gaps between both the materials and the root canal wall and within the materials. Livewire was used to select the main root canal area at each level based on the maximum diameter of the main root canal, and the isthmus area was divided by a multiple-slice edit function (Fig. 1). The total volume of the voids in the root canal, main root canal, and isthmus was obtained, and the percentage volume of voids (PVV) of each area was calculated as follows:

$$\text{Percentage volume of voids (PVV)} = \frac{\text{canal volume} - \text{fillings volume}}{\text{canal volume}} * 100\%$$

Statistical analysis

Statistical analysis was performed using SPSS 27.0 software (SPSS Inc., Chicago, IL, USA) and GraphPad 9.0 software (GraphPad Software Inc., La Jolla, CA, USA). One- ANOVA and SNK q test were performed to analyze the PAV and PVV in the different groups.

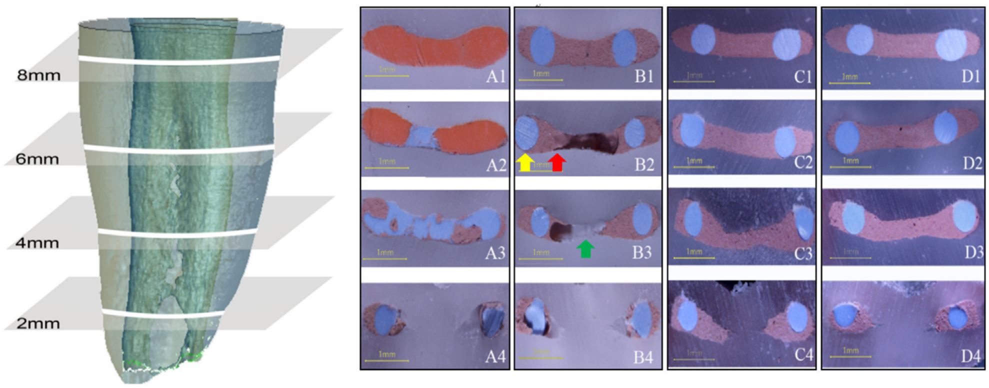

Figure 2 Representative images of the canals with isthmuses filled with different obturation methods: A1-A4. Group VC (vertical compaction obturation, control group). B1-B4. Group SCP (passive single cone). C1-C4. Group BS (bi-directional spiral). D1-D4. Group U (ultrasound); gutta-percha is indicated by the yellow arrow, sealers are indicated by the red arrow shown in B2, and voids are indicated by the green arrow in B3. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 1 The percentage area of voids (PAV) in different groups (mean%±SD).

Groups	Levels				
	2 mm	4 mm	6 mm	8 mm	Average
VC	50 ± 0.12^{Aa}	36 ± 0.13^{Ab}	24 ± 0.11^{Ab}	21 ± 0.07^{Ab}	33 ± 0.16^{A}
SCP	53 ± 0.07^{Aa}	58 ± 0.09^{Ba}	37 ± 0.05^{Bb}	30 ± 0.04^{Bb}	45 ± 0.13^{B}
BS	21 ± 0.13^{Ca}	27 ± 0.05^{Ca}	22 ± 0.05^{Ca}	17 ± 0.03^{Da}	21 ± 0.08^{C}
U	23 ± 0.14^{Ca}	24 ± 0.05^{Ca}	19 ± 0.03^{Da}	16 ± 0.02^{Da}	21 ± 0.08^{C}

Different letters indicate statistically significant differences verified by One- ANOVA and SNK q test *($P < 0.01$)*. Uppercase letters (A/B/C) indicate comparisons of groups in rows (different groups); lowercase letters (a/b) indicate comparisons of groups in columns (different levels).
BS: single cone obturation with bi-directional spiral.
SCP: passive single cone obturation.
U: single cone obturation with ultrasound.
VC: vertical compaction filling.

Results

The rhodamine-B staining test showed that the solution overflowed from the main canal to the isthmus area, and no remnants of support material were detected on histological sections. The standard deviation of the 3D-printed model was 0.034 mm, and the average fitting distance was 0.02 mm.

Fewer voids were detected in the BS and U groups than in the SCP and VC groups, with the average percentage area of voids (PAV) at all slice levels than those of the SCP and VC groups ($P < 0.01$) (Table 1). The lowest PAV of 21% was detected in the groups with sealer placement supported by bidirectional spiral or ultrasound; which was lower than those in the VC group (33%) and the SCP group (45%) ($P < 0.01$).

In different parts of the canal in each group, no significant difference was found in the PAV ($P > 0.01$) for the BS and U groups; and the PAV of the apical region for the SCP and VC groups showed more voids with respect to coronal region ($P < 0.01$).

Based on the micro-CT scans, a significant difference in the percentage volume of voids (PVV) of the total root canal was observed, and the PVV of 24% in the U group and 23% in the BS group were both lower than that of 38% in the SCP group ($P < 0.01$) (Table 2). In the isthmus, compared with the 46% PVV in the SCP group, the bi-directional spiral and ultrasound-supported sealer placement group had lower porosities, with PVVs of 25% and 29%, respectively ($P < 0.01$), and no difference was observed relative to the 24% PVV in the VC group ($P > 0.01$).

However, in the main canal, when the PVV was 22% in the SCP group and 13% in the VC group, the porosity decreased to 14% in the U group and 18% in the BS group ($P < 0.01$). In addition, the rate of overfilling was 20% in the bi-directional spiral-supported sealer group and 15% in the ultrasound group ($P > 0.01$).

Discussion

Due to advancements in 3D printing, the creation that effectively identical replicas of extracted human teeth for establishing a standard research model is possible.[16] In this study, a 3D-printed tooth model with the shape of classification of the Hsu & Kim V-type (1997)[17] and root boundary type isthmus (Yin's II),[18] which is the most common type in

Table 2 The percentage volume of voids (PVV) after different sealer placement methods (mean%±SD).

Groups	Areas		
	Total canal	Isthmus	Main canal
VC	20 ± 4^{A}	24 ± 5^{Aa}	13 ± 3^{Aa}
SCP	38 ± 3^{B}	46 ± 4^{Ba}	22 ± 4^{Bb}
BS	23 ± 2^{A}	25 ± 3^{Aa}	18 ± 1^{Ba}
U	24 ± 2^{A}	29 ± 3^{Aa}	14 ± 1^{Ab}

Different letters indicate statistically significant differences verified by One- ANOVA and SNK q test *($P < 0.01$)*. Uppercase letters (A/B) indicate comparisons of groups in rows (different groups); lowercase letters (a/b) indicate comparisons of groups in columns (different areas of canal).
BS: single cone obturation with bi-directional spiral.
SCP: passive single cone obturation.
U: single cone obturation with ultrasound.
VC: vertical compaction filling.

the isthmus of human premolars, was established as a representative of the irregular structure of the root canals based on the micro-CT data.[18–20] Additionally, as a result of the availability of the model and the limit of cleaning support materials inside the isthmus,[18] the minimum diameter (d_{min}) was designed to be 0.15 mm, and the repeatability and usability of the models were confirmed by the 3D standard deviation and average fitting distance.

In addition, to evaluate the overall quality of the root canal fillings, the presence and distribution of voids in canals with a simulated band-shaped isthmus after obturation were evaluated by the combination of the 2D slice technique and the 3D micro-CT method. The percentage area of voids (PAV) and the percentage volume of voids (PVV) were used as the 2D and 3D parameters, respectively, and overfilling was used as a safety indicator.

The findings of this study indicated that the supported sealer placement methods could decrease the voids in the canal fillings and improve the filling quality of single cone obturations (SC). With the help of bi-directional spiral (BS) and ultrasonic (U) methods, the total percentage area of voids decreased from 45% to 21%, almost half of the porosity of the single cone obturation. In the SC group, significantly greater porosity was observed in the apical area than in the coronal area, but with the help of BS and U, the filling quality in the apical area was especially improved.

Moreover, 3D micro-CT revealed a significant improvement in the filling quality of the isthmus. After BS and U-supported sealer placement, the percentage of voids in the isthmus decreased by 17%–21% compared with that after SC obturation; which obtained equivalent filling quality to the vertical compaction obturation (VC). However, in the main canal, the PVV with the help of BS and U was only decreased by 4%–8% than SC. Therefore, placing the sealer with the support of BS and U could improve the quality of the canal with the isthmus.

The most popular sealer placement method in the clinic involves the use of a master cone or the injection of sealers from the needle,[21] however, in this study, BS and ultrasound were also used to improve the filling quality. As an instrument for assisting canal obturation, the design of BS with its upper part rotates the sealer downwards to the apical foramen to carry it apically, and the tip part rotates the sealer upwards to the crown to prevent overfilling, make it improve the sealer distribution.[22,23] Previous studies have shown that lentulo-supported sealer placement could cover 95%–100% of the perimeter of the root canal wall and reduce voids compared with the use of a master cone to insert the sealer into a 30-40-degree curved canal.[14,24]

The way ultrasound could improve the distribution of sealers in canal with isthmus may be by rearranging the particles inside the sealer, promoting the escape of air, and thus reducing the porosity of the fillings.[3,15] As expected, the use of ultrasound directly in sealers or indirectly through the master cone or instrument can result in a greater distribution of fillings and better filling quality with the single cone obturation than the continuous-wave technique.[25,26]

In this study, it was shown that a BS with speed of 2000 rpm or an ultrasound tip with a power setting of 6 was inserted from the root canal orifice to the distance of WL-2mm for 2s to introduce sealers gradually, can improve the filling quality of single cone obturation in the canal with isthmus. However, no difference was observed between the BS and ultrasound-supported sealer placement methods in terms of the effectiveness of filling the isthmus, only the rate of overfilling was 20% for BS compared with 15% for ultrasound due to concerns regarding safety and fewer postoperative reactions.

Furthermore, the results from this study also showed that the obturation of irregular anatomical structures such as the isthmus was still challenging for the single-cone obturation technique. In the area of the isthmus, almost twice as many voids (46%) were entrapped in the material after single cone obturation compared with 25% after vertical compaction obturation, whereas the porosities of the main canal were only 22% in the SC and 13% in the VC. Even after the use of supported sealer placement methods, 25%–29% porosity was still found in the isthmus. Similar findings were also reported in previous research; the average porosity after single cone obturation in the canal with the isthmus was approximately 6.52%–22.98%; significantly greater than the porosity of 3.91%–13.11% in the VC.[9,11,12] Therefore, more improvement measures are still needed to improve the filling quality of the canal isthmus.

In this study, root canal filling quality in a canal model with a Hsu & Kim V-type and root boundary-type isthmus was evaluated, and additional studies on the optimal single cone obturation technique for various canal morphologies are needed.

In conclusion, in this vitro study, bi-directional spiral or ultrasound-supported sealer placement improved the single cone obturation quality in irregular canal structures with isthmus areas, and ultrasound provided less sealer overfilling.

Declaration of competing interest

The authors declare that they have no conflict of interest.

Acknowledgments

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