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ORIGINAL ARTICLE

The shaping and cleaning abilities of self-adjusting files in the preparation of canals with isthmuses after glidepath enlargement with ISO or ProTaper Universal NiTi files

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Abstract
Background/purpose: This study compared the shaping and cleaning ability of self-adjusting files (SAF) after glidepath enlargement with ISO NiTi files (Group I) or ProTaper Universal (PTU; Group II) for preparing maxillary premolar canals with isthmuses.
Materials and methods: Twenty-eight teeth containing isthmuses were scanned preoperationally after glidepath enlargement and preparation with SAF ($n = 14$). Changes in canal and isthmus volume, prepared surface, debris volume, and transportation were determined. Data were compared by t test between groups and paired t test within each group.
Results: No difference was observed regarding changes in canal volume or prepared surface between the two groups ($P > 0.05$). Paired t tests showed that the coronal and middle prepared areas of the canal after using SAF in Group I were statistically larger than those using ISO files, whereas the use of an adjuvant preparation with SAF after PTU resulted in a significant increase in the apical prepared area in Group II. ISO and SAF systems deviated less from the center than did PTU and SAF systems at most sections. After the use of SAF, isthmus volumes were significantly increased within each group ($P < 0.05$). Although less debris resulted from the use of SAF instruments as compared to glidepath instruments, there was no significant difference between both groups ($P > 0.05$).

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Conclusion: SAF following glidepath enlargement with ISO files could improve preparation of the coronal and middle part of the canals, and adjuvant preparation with SAF after using large-taper instruments increased the apical prepared area.

Introduction

The goal of endodontic therapy is the removal of all infected or necrotic tissue, microorganisms, and microbial byproducts from the root canal system. However, it is difficult to achieve thorough debridement of the entire root canal system due to the intricate nature of the morphological anatomy, particularly of teeth containing isthmuses, anastomoses, and/or other canal irregularities.[1–3] Isthmuses are defined as narrow ribbon-, fin-, or web-shaped communications between two root canals. In roots with two canals, isthmuses are highly prevalent, such as the mesial roots of maxillary and mandibular molars, the distal root of mandibular molars, the maxillary and mandibular first and second premolars, and mandibular incisors.[4–6] Furthermore, the buccolingual orientation of isthmuses does not permit radiographic detection before the endodontic procedures, further aggravating the difficulties inherent in root canal debridement.

As the most widely used files for root canal preparation, rotary files have a spiral blade arranged in a helical formation. When rotated, they machine a central portion of the root canal into a round cross-section, but the buccal/lingual areas of flat root canals and areas facing the isthmus in tear-shaped canals cannot be adequately prepared.[7,8] Furthermore, hard-tissue debris in the root canal system mainly accumulates in the isthmus area, as discovered using microcomputed tomography (MCT) or histologic evaluation.[1,8] Although untouched areas and debris can theoretically be treated by the following chemical debridement, these isthmuses and other canal irregularities make irrigant penetration difficult, resulting in ineffective dissolution of hard-/soft-tissue remnants and microorganism destruction. Consequently, isthmuses often harbor tissue, microbes, and debris after instrumentation, potentially providing space and nutrition for bacterial growth and/or future bacterial recontamination of the root canal.[1,8]

The self-adjusting file (SAF; ReDent-Nova, Ra'anana, Israel) was designed to address the shortcomings of traditional rotary files by adjusting itself three-dimensionally to the shape of the root canal. This instrument is operated with reciprocating vibrating handpieces, and its hollow design allows for continuous delivery of irrigant throughout the procedure via a special rinsing unit.[9] To date, root canal preparation with the SAF has been quantitatively and qualitatively described in several studies.[10–13] MCT-based studies showed that the percent of root canal area affected by the SAF method is higher than that affected by popular rotary instrumentation.[10,12,14] Additionally, SAF is significantly more effective than rotary NiTi instrumentation in eliminating debris and viable *Enterococcus faecalis* cells in long oval root canals.[15–19] Consequently, it is supposed that SAF has superior potential to treat more area of the isthmus and eliminate debris produced by rotary canal preparation.

According to the description by Metzger et al,[9,20] a 1.5-mm SAF may easily be compressed to the extent where it can be inserted into any canal previously prepared or negotiated with a #20 K-file, and a 2.0-mm file can easily be compressed into a canal prepared with a #30 K-file. In fact, the average diameter of a biological apex is 0.08 mm to 0.3 mm,[21] therefore, the use of a SAF alone is unable to adequately prepare the root canal. Currently, the glidepath used for SAF preparation is ISO K files.[9,12] However, insufficient apical preparation and inadequate apical irrigation with SAF after ISO K files instrumentation has been reported.[22] This observation suggests that root canal debridement is improved with progressively larger instrumentation through removing more contaminated dentin and providing better access for efficient irrigation and disinfection of the canal system. The purpose of this study was to compare the shaping and cleaning abilities of the SAF after glidepath enlargement with ISO NiTi files or ProTaper Universal (PTU) for preparing maxillary premolar canals with isthmuses.

Materials and methods

Selection of teeth

Mature single-root maxillary premolars were collected from a native Chinese population. All teeth were extracted for orthodontic reasons, and written consent was obtained from the patients. Teeth were excluded if there were extensive caries, fractures, or prior endodontic treatment. Attached soft tissue and calculus were removed using an ultrasonic scaler, and the teeth were stored in 0.1% thymol solution at 4°C until further use.

Radiographs were taken of the teeth from the mesiodistal directions and scanned using a desktop X-ray microfocus CT scanner (ZKKS-MCT-Sharp, Guangzhou, China) at an isotropic resolution of 20 μm. The system consisted of a sealed X-ray tube operated at 75 kV/133 μA. Teeth containing type IV isthmuses described by Hsu and Kim[23] were selected and accessed using high-speed diamond burs. The instruments were gently introduced by hand to working length in ascending order beginning with #8 K files (Dentsply Maillefer, Ballaigues, Switzerland), and the first binding file was termed as the initial apical file. Canal curvatures were assessed according to Schneider's technique.[24] A total of 28 teeth with curvatures of $< 20°$ and initial apical files of $<$ #15 were selected. Canal lengths and patency were determined using size #10 K files, and the working length (WL) was established at 1 mm shorter than the length of the root. The glidepath of all of the teeth was confirmed to a size #15 K file (Dentsply Maillefer). Specimens were then randomly allocated to two groups (n = 14 each) based on the preparation protocols used. The sample size was based on a pilot study and related research.[10] All root canal treatments were carried out by a single doctor who had been specifically trained to operate the SAF instrument and had more than 10 years of clinical experience with NiTi rotary instruments.

Group I: Glidepath enlargement with ISO NiTi files and SAF preparation

Canals in Group I were first prepared to the WL using ISO instruments 25/02 and 30/02 (Hero642; Micromega, Besançon, France). The average WL in this group was 20.3 mm (range, 19–22.5 mm). NaOCl (1.3%) and EDTA (17%) were delivered in a syringe with a 30-gauge needle as deep as possible to 1 mm from working length as the irrigant (2 mL NaOCl and 6 mL EDTA per canal each time). After being prepared to size #30, canals were irrigated with 5 mL 1.3% NaOCl. The teeth were then subjected to a postoperative MCT scan. Thereafter, the canals were prepared using 2.0-mm diameter self-adjusting files (SAF-2.0; ReDent-Nova). The SAF was operated using an in-and-out vibrating handpiece at 5000 vibrations/min and 0.4-mm amplitude.[9] A special irrigation device (VATEA; ReDent-Nova) was connected to the irrigation hub on the file, enabling irrigant to be delivered at a flow rate of 5 mL/min. During the first 2 minutes, 1.3% NaOCl was used, which was followed with 1 minute of EDTA irrigation and another 1 minute of NaOCl irrigation per canal. The total volume of NaOCl and EDTA used for this group was 24 mL and 17 mL per canal, respectively. The teeth were scanned using the MCT.

Group II: Glidepath enlargement with PTU and SAF preparation

Canals in Group II were prepared with six PTU rotary instruments (Dentsply Maillefer) in the sequence recommended by the manufacturer (Sx, S1, S2, F1–F3). The average WL in this group was 20.5 mm (range, 18–22.5 mm). Two milliliters of 1.3% NaOCl and 17% EDTA were used to irrigate the canal between each instrument according the method described for Group I. After F3 instrumentation, the canal was irrigated with 7 mL of 1.3% NaOCl and scanned with MCT. Then canals were prepared using SAF-2.0 under irrigation with 1 minute of EDTA and 1 minute of 1.3% NaOCl per canal and delivered as previously described. The volume of NaOCl and EDTA used for this group was equal to that for Group I. The teeth were then scanned for a third time with the MCT.

Evaluation

MCT data were reconstructed from the biological apex to the level of the cementoenamel junction. Precise repositioning of pre-preparation and various post-preparation images was ensured by combining a custom-made

Table 1 Increased volumes of canals, isthmuses, debris, and prepared rate of maxillary premolar root canals after the use of various instruments.[a]

Instruments		Canal Volume (Δ %)				Prepared rate (%)				Isthmus volume (Δ %)	Debris volume (mm^3)
		Total	Coronal	Middle	Apical	Total	Coronal	Middle	Apical		
Group I	ISO	22.15 ± 15.40	19.79 ± 13.28	22.95 ± 14.63	47.00 ± 45.18	64.52 ± 14.37	60.53 ± 16.78	63.27 ± 14.5	71.34 ± 7.22	14.10 ± 9.10	0.075 ± 0.066
	ISO&SAF	55.51 ± 32.50*	50.32 ± 26.48*	60.83 ± 41.16*	89.15 ± 82.22*	83.91 ± 9.98*	84.06 ± 7.03*	84.51 ± 6.27*	78.51 ± 16.35	33.97 ± 24.44*	0.041 ± 0.038
Group II	PTU	56.81 ± 18.20	49.17 ± 17.72	73.70 ± 28.39	72.72 ± 31.82	82.87 ± 10.96	86.20 ± 3.40	86.99 ± 5.46	70.00 ± 14.50	26.25 ± 16.46	0.079 ± 0.070
	PTU&SAF	69.17 ± 18.96**	60.33 ± 20.83**	87.77 ± 26.16**	89.33 ± 36.63**	86.14 ± 8.57**	87.26 ± 2.07	87.61 ± 4.32	79.44 ± 14.27**	35.14 ± 19.33**	0.057 ± 0.046

* Significant differences within Group I (paired t test; $P < 0.05$).
** Significant differences within Group II (paired t test; $P < 0.05$).
ISO = ISO NiTi files; PTU = ProTaper Universal rotary files; SAF = self-adjusting files.
[a] No significant differences were observed between Groups I and II ($P > 0.05$).

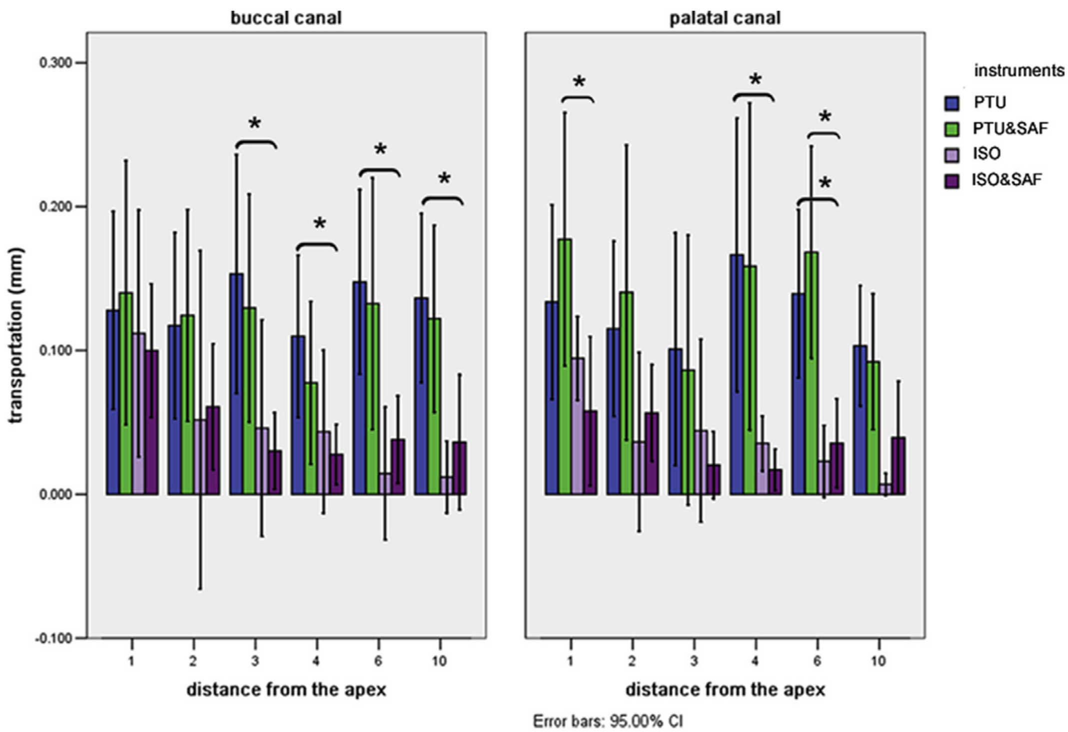

Figure 1 The transportation of maxillary premolar root canals after the use of various instruments. Significant differences between PTU or PTU&SAF in Group II and ISO&SAF in Group I are noted. No statistical difference was observed between groups ($P > 0.05$). * Significant differences within groups I and II (t test; $P < 0.05$). PTU = ProTaper Universal rotary files.

mounting device with a software-controlled iterative superimposition algorithm (the ImageFusion module in the software MedINRIA, Paris, France). The resulting color-coded root canal models (in which red indicates preoperative canal surfaces, green indicates postoperative canal surfaces, and yellow indicates hard-tissue debris) enabled quantitative comparison of the matched root canals before and after shaping. Subsequently, changes in canal volume, prepared canal surface, isthmus volume, debris volume, and transportation were measured after the use of each instrument system, and the apical diameter was designated as the maximum mesiodistal diameter of the canal at the section 1 mm from the apex.

Matched images of the surface areas of the canals, before and after preparation, were examined to evaluate three-dimensionally the amount of instrumented area. Prepared root canal surface was expressed as a percentage of the number of affected surface voxels to the total number of surface voxels. Isthmuses were segmented according to the principle that isthmuses with mesiodistal widths equal to one quarter of the diameter of the main canals were identified as the starting and ending points in the oro-palatal direction,[1] and the volumes of the isthmuses were calculated. The debris after instrumentation was identified and calculated as follows: black-colored voxels were identified as soft tissue, liquid, or air (black color) in the preoperative scan; in the second scan, voxels that had changed from black to white were assumed to be dentin debris.[8] The amount of transportation at the 1-, 2-, 3-, 4-, 6-, and 10-mm points from the apical foramen was measured from the cross-sectional images before and after the canal preparation according to the following method modified by Gergi et al.[25] The formula:

$$(a1 - a2) - (b1 - b2) \quad (1)$$

was used to calculate the amount of transportation: a1 was the shortest distance from the mesial edge of the uninstrumented canal to the mesial edge of the root, and a2 was the shortest distance from the mesial edge of the instrumented canal to the mesial edge of the root; b1 was the shortest distance from the distal edge of the uninstrumented canal to the distal edge of the root, and b2 was the shortest distance from the distal edge of the instrumented canal to the distal edge of the root.

Because normality assumptions were verified using the Shapiro-Wilk test, the results were statistically analyzed using a *t* test between groups I and II, and a paired *t* test within groups. The null hypothesis was set at 5%.

Results

The average preoperative volumes (mm^3) of canals in Groups I and II were 15.303 ± 2.900 and 14.589 ± 3.644, respectively, and the volumes of the corresponding isthmuses were 0.931 ± 0.221 and 0.948 ± 0.360, respectively. The apical diameter (mm) of the first, second, and third scans was 0.132 ± 0.048, 0.327 ± 0.098, and 0.404 ± 0.074, respectively, for Group I, and 0.138 ± 0.059, 0.323 ± 0.090, and 0.408 ± 0.087, respectively, for Group II. There was no significant difference between groups regarding canal and isthmus volume and apical diameter before treatment ($P > 0.05$).

No significant difference between Groups I and II was observed regarding the increases in volume and prepared rate ($P > 0.05$). Paired *t* tests showed that coronal and middle prepared areas of the canal obtained after using SAF in Group I were statistically higher than those obtained using ISO files, but no difference was observed for the apical prepared area within this group. By contrast, additional preparation with SAF following PTU resulted in a significant increase in the apical prepared area, while no difference was observed for the coronal and middle parts. Within-group isthmus volumes were significantly increased after the use of SAF instruments for both groups ($P < 0.05$; Table 1). Compared with using the glidepath system, relatively less debris was present after using SAF instruments, although no significant difference was noted ($P > 0.05$; Table 1). Neither technique removed debris completely from the canals or the isthmuses.

Canal transportation was 0.046 ± 0.059 and 0.122 ± 0.110 in Groups I and II, respectively. At 1 mm, 2 mm, 3 mm, 4 mm, 6 mm, and 10 mm from the apical foramen, the mean degrees of buccal or palatal canal transportation observed after using various instruments are shown in Figure 1. There was no difference in the extent of transportation between buccal and palatal canals ($P > 0.05$). ISO and SAF systems deviated less from the center as compared to PTU and SAF systems at most of the sections, especially at sections in the middle part of the canal ($P < 0.05$; Figure 1).

Color-coded superimposed models of pre- and postoperative MCT data demonstrated an obvious increase in

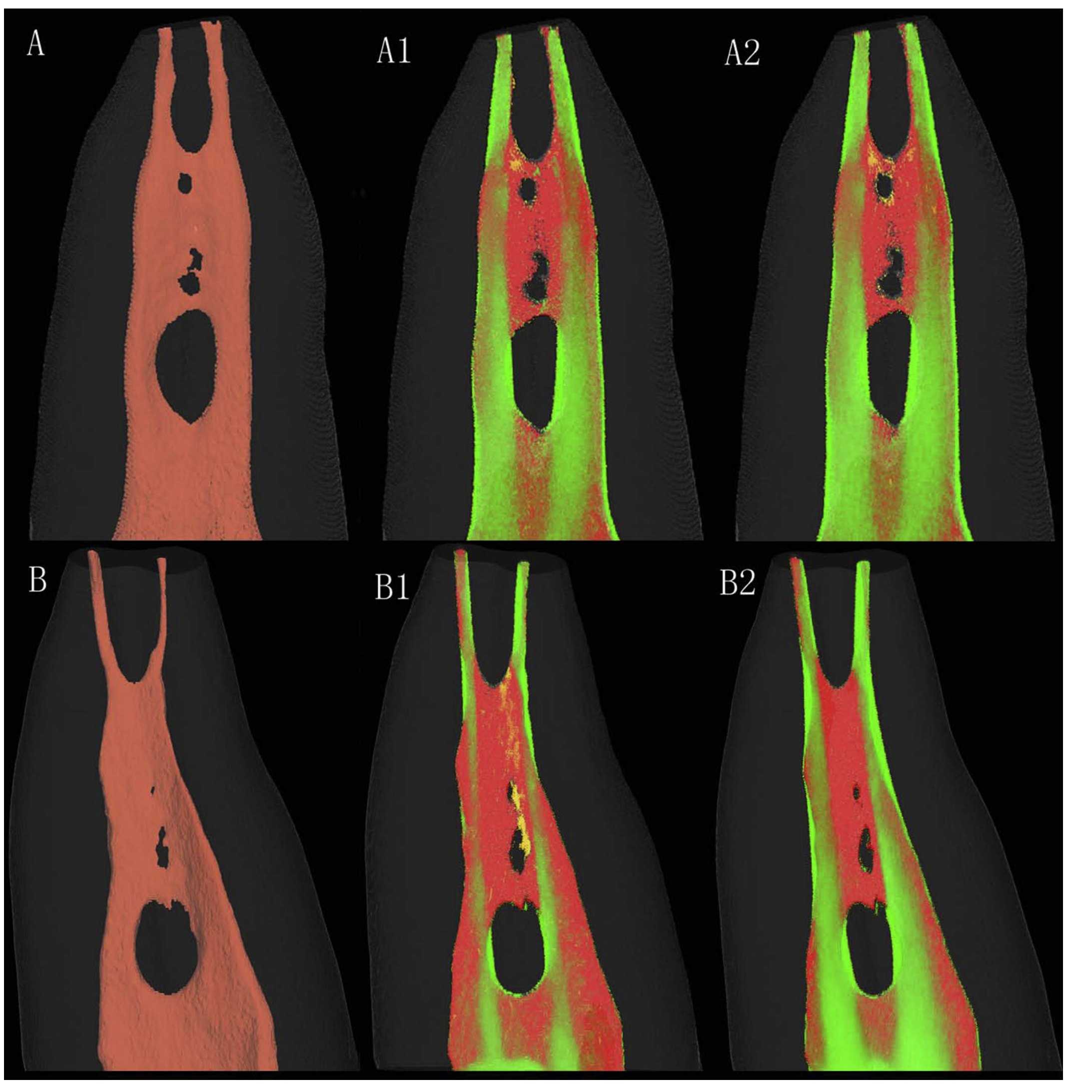

Figure 2 Three-dimensional reconstruction and superimposition of MCT scans of the root canal system of the maxillary premolar under investigation. (A,B) The initial canal configuration showing the complex isthmus area. The top root canals were prepared using (A1) ProTaper Universal as glidepath enlargement and then using (A2) SAF, and the bottom root canals were prepared using (B1) ISO files as glidepath enlargement and then using (B2) SAF. (A1,2, B1,2) Superimposed MCT reconstructions after instrumentation. Prepared areas, untouched areas, and hard-tissue debris are indicated in green, red, and yellow, respectively. ISO = ISO NiTi files; MCT = microcomputed tomography; SAF = self-adjusting files.

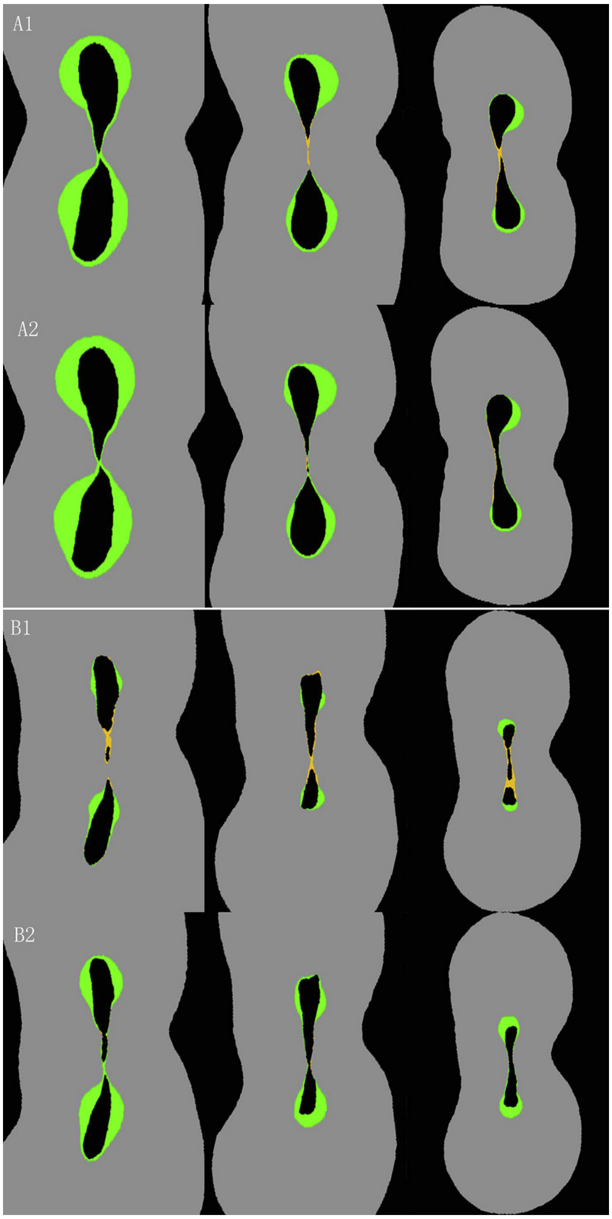

Figure 3 Cross-sections of maxillary premolar root canals after the use of various instruments on the (left) coronal, (middle) middle, and (right) apical parts. The root canals were prepared using (A1) ProTaper Universal as glidepath enlargement and then using (A2) SAF. Other root canals were prepared first using (B1) ISO files as glidepath enlargement and then using (B2) SAF. Prepared canal areas and hard-tissue debris areas are indicated in green and yellow, respectively.

prepared canal surface and volume, and a decrease in debris when canals were prepared using SAF in Group I. In Group II, the morphology slightly changed and the amount of debris notably decreased (Figures 2 and 3).

Discussion

The SAF is a hollow file designed as a compressible, thin-walled, pointed cylinder composed of a 120-mm-thick nickel-titanium lattice. This tool adapts itself to the shape of a canal both longitudinally and along the cross-section, and has many other advantages, including less instrument separation and less preparation error.[20,26] According to the instructions, glidepath must be confirmed to size #20 or #30 before using SAF. In previous studies, K files were usually used for glidepath enlargement, and changes in the root canal before and after SAF preparation were seldom investigated. Compared with K files, rotary files had been found to be more efficient, with less transportation observed. Therefore, ISO rotary files were chosen, and the shaping and cleaning efficiency of ISO and SAF were evaluated and compared with that of PTU and SAF in this study. MCT scanning has been increasingly used in recent years for studies of root canal preparation with different chemomechanical techniques.[8,10,12] Exact superimpostion ensured by software offers a noninvasive reproducible technique for three-dimensional quantitative and qualitative assessment of increases in volume and debris in prepared areas of root canal systems.

The ISO and SAF system preparation removed a relatively uniform dentin layer from the canal circumference, and also deviated less at most sections relative to the PTU or PTU and SAF system. After instrumentation with larger taper PTU files, adjuvant preparation with SAF exhibited little impact on the morphology of the middle and coronal parts. This result suggested that assisted preparation with SAF after ISO files can personalize the shaping and cleaning of the middle and coronal parts of the canal according to the anatomy of each root canal, thereby reducing the occurrence of complications, such as transportation, caused by larger tapered files.

It was reported that SAF preparation can result in insufficient apical preparation and inadequate apical irrigation.[22] Consistent with these results, we also observed less prepared areas in the apical part of the canal as compared with the coronal and middle parts. However, adjuvant preparation with SAF after PTU significantly increased the preparation rate of the apical part. The increased preparation rate might be due to the expanded coronal part produced by larger tapered files, which provided better access for apical preparation with SAF. Therefore, the PTU and SAF hybrid techniques could be recommended to prepare wider root canals.

Regarding the preparation of isthmuses, paired *t* tests showed that volumes of isthmuses after SAF preparation increased significantly in both groups. Although debris was found to accumulate in isthmuses after rotary file preparation in several studies,[8,27] only a few evaluated the volume changes of isthmus after mechanical preparation. Markvart et al[28] found that the unprepared areas of isthmuses were 17.6%, and a minor reduction in the isthmus volume was noticed, which might result from the accumulation of debris and crossing the isthmus of root canal instruments. The canals selected for the present study mainly contained type IV isthmuses. The SAF adjusted itself three-dimensionally to the shape of the root canal and removed the dentin from the tear-shaped areas of the isthmuses. However, the SAF reduced the accumulation of hard-tissue debris in the isthmus due to the application of continuous irrigation through the hollow file, which resulted in the volume increase observed in the isthmuses.[27]

It was recently reported that the use of SAF in the mesial roots of mandibular molars resulted in less hard-tissue debris accumulation as compared to when rotary files were used. This could be attributed either to avoiding rotary motion in the canals or the continuous irrigation applied through the hollow file throughout the procedure, or both.[27] However, in our study, no significant difference was observed in debris volume, either within or between groups. The possible reason for this might be that the isthmuses of maxillary premolars are wider and more mutable than those of mandibular molars, which results in amounts of debris too low to compare.

In conclusion, the SAF following glidepath enlargement with ISO NiTi files improved the preparation of the coronal and middle part of the canals, and resulted in less transportation. Adjuvant preparation with SAF after the use of large-taper instruments increased the apical prepared area, and can be recommended to prepare wider root canals. Both techniques improved the debridement efficacy with relation to isthmuses, but a small amount of debris was also observed in the isthmuses after both techniques.

Conflicts of interest

The authors have no conflicts of interest relevant to this article.

Acknowledgments

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