Evaluation of Three Ni-Ti Systems in Retreatment of Curved Root Canals Obturated by Gutta-Percha With iRoot SP

Yi Chen
College of Stomatology, Tianjin Medical University
Weiping Tian
Tianjin Medical University
Lisha Wang
College of Stomatology, Tianjin Medical University
Fan Qi
College of Stomatology, Tianjin Medical University
Mengyu Sun
Tianjin Medical University
Rong Li
College of Stomatology, Tianjin Medical University
Kehua Que (kque@tmu.edu.cn)
College of Stomatology, Tianjin Medical University

Research Article

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Abstract

Background

To evaluate the retreatability of curved root canals obturated with gutta-percha (GP) and iRoot SP using three different Ni-Ti systems through micro-computed tomographic (micro-CT) analysis.

Methods

A total of 51 curved root canals of permanent molars with angles of curvature ranging from 20° to 40° were used. The root canals were prepared with the ProTaper Next (PTN) rotary system to size 25, .06 taper and filled with iRoot SP and GP using the single cone technique. Samples were randomly divided into three groups (n = 17 each) according to the retreatment system used: Group I. ProTaper Universal Retreatment (PTR) system + ProTaper Next system up to PTN X2; Group II. Waveone Gold (WOG) system (WOG25); Group III. Reciproc Blue (RB) system (RB25). The ability to regain apical patency, the volume of residual filling material, and dentinal microcrack were assessed using micro-CT imaging. Data were analyzed statistically using two-way analysis of variance and chi-square test with a significance level of 5%.

Results

There were no significant differences among the systems tested in the reestablishment of apical patency and reduction of filling materials ($P > 0.05$), but RB system exhibited better reestablishment root canal ability in the upper portion of curvature and the reduction of filling materials in the apical third ($P < 0.05$). Intergroup analysis indicated that PTR system induced significantly more dentinal microcracks than other two systems ($P < 0.05$).

Conclusions

All three tested Ni-Ti instruments showed the similar retreatability of curved root canals obturated with gutta-percha and iRoot SP. RB system may be more effective and safer in curved root canal retreatment.

Background

Root canal retreatment aims to remove existing root filling materials and reestablish patency of canals. It has been the first nonsurgical treatment option after root canal treatment failure [1]. Apart from retreatment techniques and instrumentations, the types of filling material directly affect with its removal [2]. Recently, bioceramic-based sealers, such as iRoot SP, EndoSequence BC Sealer, and MTA-Fillapex, have been applied to obturate root canals due to their superior bioactivity and biocompatibility [3, 4]. As a calcium silicate-based bioceramic sealer, iRoot SP has performed a promising result in root canal filling and gained popularity in clinical discipline [5]. Its fine particle structure is beneficial to increase fluidity to fill difficult-to-access areas, such as irregularities of dentine, isthmus, and accessory canals [6]. Studies have demonstrated micromechanical anchorage as well as chemical adherence of iRoot SP to the dentine, establishing strong bond, which may increase the fracture resistance of roots [7, 8]. However, the higher hardness upon the setting hinders its removal during retreatment [2, 9, 10], thereby posing a challenge to clinicians.

Numerous studies presented that some mechanical nickel-titanium (Ni-Ti) instruments, in particular rotary and reciprocating systems, exhibited efficiency in root canal retreatment [11, 12, 13, 14, 15, 16, 17]. In these studies, Protaper Universal Retreatment (PTR) system, Waveone Gold (WOG) system, and Reciproc Blue (RB) system are regularly applied to curved root canal retreatment. As a continuous rotary system, PTR system includes three instruments (D1, D2, and D3) with a convex triangular cross-section, and only the D1 instrument has an active working tip, which could promote penetration and reduce the incidence of stripping, perforation, and ledging during retreatment [18]. Preliminary studies have suggested that PTR system can remove iRoot SP from straight canals [2, 9]. WOG and RB systems belong to the single-file reciprocating system, with golden and blue appearances, respectively. Both approaches possess high flexibility and cyclic fatigue resistance after repeated heat treating and cooling production processes [19, 20]. In addition, the design of cross-section is different; alternating off-centered parallelogram-shaped in WOG, S-shaped in RB, and a larger rotation angle of reciprocating movement for WOG system [21]. They have shown good results in removing epoxy-resin based sealer from curved canals in laboratory research [14, 15, 16].

In the retreatment procedure, canals with greater curvature increase the incidence of complications, such as ledge and dentinal crack formation, apical transportation, or perforation, thereby decreasing the root strength and long-term efficacy [15]. Thus far, the performance of these types of instruments has been tested in curved canal retreatment, but few researchers focus on their application to the removal of bioceramic sealers in curved canals. Therefore, this study aims to evaluate the retreatability of curved root canals obturated with gutta-percha (GP) and iRoot SP using PTR, WOG, and RB Ni-Ti systems, including the ability to regain the patency, the remaining filling amount and dentinal microcrack formation by applying higher resolution micro-computed tomographic (Micro-CT) imaging.

Methods

Sample selection

This experiment has been approved by the Ethics Committee of the Hospital of Stomatology, Tianjin Medical University (no. TMUhMEC2020115). A total of seventy-eight human molars were obtained from the oral surgery department due to periodontal disease. The molars were cleaned, disinfected, and stored in 0.1% thymol solution at 4°C. The teeth were selected by CBCT (KaVo Dental, Germany) scanning without canal calcification, immature apex, previous canal treatment, fracture or crack, double curvatures and with oval canals, only one root canal or two distinct canals from the pulp chamber to the apex. After scanning, angles and radius of curvature were measured using eXamVision (KaVo Dental, Germany) and ImageJ (Version 1.46r; National Institutes of Health, Bethesda, MD) software. The root canal angles and radius were measured by the methods of Schneider [22] and Schafer et al [23] in bucco-lingual and mesio-distal directions, and root canals with a curvature between 20° and 40° and a radius between 4 and 10 mm in at least one direction were included in the study. Only mesial roots from mandibular molars and mesio-buccal roots of maxillary molars were selected and separated after the tooth crown was removed. Finally, fifty-one teeth were used as the samples.

Root canal preparation and filling

When the access cavity of each root was prepared, the canal patency was confirmed by the insertion of a size 10 K-file (Dentsply Sirona Endodontics, Ballaigues, Switzerland), and the working length (WL) were determined to be 1 mm short of the apical foramen. Teeth with apical foramen having diameters smaller than those of a size 10 K-file or larger than those of a size 20 K-file were not included. All root canals were prepared with the ProTaper Next (PTN) rotary system (Dentsply Sirona Endodontics) in the sequence recommended by the manufacturer up to X2 (tip size .25, .06 taper). Each instrument was used to prepare a maximum of five canals. Throughout the preparation procedures, the canals were irrigated with 2 mL 1% sodium hypochlorite (NaOCl) using 30-G needle (Ultradent Products Inc, South Jordan, UT, USA) after each instrument withdrawal. After completion preparation, the final irrigation was performed for 1 minute with 2mL 15% EDTA, 30 seconds with 2 mL 1% NaOCl, and 30 seconds with 2mL distilled water. The canals were dried with sterile PTN X2 paper points (Dentsply Sirona Endodontics) and were filled with a bioceramic sealer (iRoot SP, Innovative BioCeramix Inc, Vancouver, BC, Canada) and gutta-percha (GP) point PTN X2 by using the single cone technique. The filling procedure with iRoot SP was performed by positioning the syringe tip inside the root canal and injecting the sealer according to the manufacturer’s recommendation. Then, the gutta-percha was adjusted to the WL and cut at the level of the orifice and slightly condensed with a plugger. The crowns were sealed with a temporary restoration material (Caviton, GC, Tokyo, Japan), and the quality of the root canal filling was evaluated by micro-CT scanning. Finally, all samples were maintained at 37°C and 100% humidity for four weeks.

Root canal retreatment

Temporary restorations were removed, and then followed by the GP in the coronal third (3 mm) using a number 2 Gates Glidden drill (Dentsply Sirona Endodontics). Subsequently, the samples were randomly divided into three experimental groups ($n = 17$). The same experienced endodontic specialist performed retreatment procedure, and each instrument was used to prepare three canals.

Group I: ProTaper Universal Retreatment (PTR) system + ProTaper Next rotary system

According to the manufacturer’s instructions, the PTR system (Dentsply Sirona Endodontics) was used at a rotation speed of 300 rpm and torque of 2.5 N/cm^2 with an endodontic motor (X-Smart, Dentsply Sirona Endodontics). The filling materials in coronal portion were removed by the D1 file, by the D2 file in the middle portion, and by the D3 file in the apical portion. After the removal procedure, the PTN X2 instrument was used to prepare the canals to achieve the same apical size as the other two groups. Throughout the process, the canal was irrigated with 2 mL 1% NaOCl after each instrument withdrawal.

Group II: WaveOne Gold (WOG) system

The WaveOne Gold primary instrument (tip size 25; variable taper; Dentsply Sirona Endodontics) was used at the reciprocation WAVEONE ALL mode with the VDW Gold motor. The file was introduced into the root apex of each filled root canal by using an in-and-out pecking motion via light apical pressure within 3 mm range. The file was extracted and cleaned after three pecking motions, and the canal was irrigated with 2 mL 1% NaOCl. The procedure was repeated until the file reached the WL.

Group III: Reciproc Blue (RB) system

The Reciproc Blue R25 file (tip size 25; variable taper; VDW, Munich, Germany) was used in the same way as described for the WOG system at the reciprocation RECIPROC ALL mode with the VDW Gold motor.

In the retreatment process, once the instrument encountered blockage, the retreatment should be stopped and the sample was scanned with Micro-CT. All samples were irrigated for 1 minute with 2 mL 15% EDTA, 30 seconds with 2 mL 1% NaOCl, and 30 seconds with 2 mL distilled water.

Micro-CT scanning

The SkyScan 1276 micro-CT device (Bruker micro-CT, Kontich, Belgium) was used to scan the samples after the filling and retreatment procedures. The samples were scanned at 10.05 μm pixel size, 90 kV voltage and 111 μA current; 180° rotation around the vertical axis with a rotation step of 0.4°. After scanning, the images were reconstructed using the software NRecon (Bruker micro-CT).

The ability to regain the patency

The method Schneider and Schafer used was modified to divide the curved part of root canals. The arc between the point A where the curved root canal begins to bend and the apical foreman (point B) was assumed to be a segment of a circle. The arc between AB was divided into three equal portions, namely, upper portion, middle portion, and lower portion (Fig. 1A). The number of samples in each group that regained the apical patency was recorded. For the canals failed to regain the patency, the 3D models were reconstructed to evaluate which curved part (upper, middle, and lower) the preparation terminal points were located in. In order to analyze the reasons failed to regain the patency, the coronal, sagittal, and transaxial section changes of all samples were observed. The number of the samples which exhibited ledge formation and iRoot SP resistance was recorded.

Remaining filling amount

The volumes of the filling material were analyzed using the CTAn v.1.17.9.0 program (Bruker micro-CT) during the pre- and post-retreatment procedure.

Dentinal microcrack evaluation

Reconstructed image stacks were transferred to the DataViewer software, and each sample was recorded from coronal, sagittal, and transaxial sections, thereby produced a 3D image. The cross-sectional images (N = 50,754) of the samples pre- and post-retreatment procedure were opened and evaluated simultaneously. They were compared twice by two blinded observers, and the formation of microcracks were identified and recorded. The internal surface of the root canal or external root surface without any defects were defined as having ‘no defect’; all the defects (eg, craze line, partial crack, fractures, or microcracks) were defined as ‘defects’ [24]. In cases of disagreement between the observers, images were reexamined until consensus was reached.

Statistical analysis

Normality of variable distribution was evaluated with the Kolmogorov-Smirnov test. Then, the initial filling material volume and the reduction rate were statistically analyzed using two-way analysis of variance and Tukey’s multiple comparisons test. Statistical analysis for the other data were performed using Fisher exact test. The statistical significance level was set at $P < 0.05$. Statistical analyses used SPSS version 23.0 (SPSS Inc, Chicago, IL).

Results

As shown in Table 1, the percent of the samples reestablished canal patency successfully in each group were 58.82% (PTR), 64.71% (WOG), and 82.35% (RB). For the samples failed to regain the patency, different terminal points (Fig. 1B-D) post-retreatment are also presented in Table 1. There was a significant difference in the terminal points of root canal retreatment occurred in the upper portion among three groups ($P < 0.05$). In terms of the reasons for failure to regain the patency, ledge formation (Fig. 1E and F) and iRoot SP resistance (Fig. 1G and H) were presented in all three groups, and no statistical difference was found among the groups ($P > 0.05$).

Table 1
Numbers and percent of samples with different terminal points of root canal retreatment, and the reasons for failure to regain the patency

	Apical Patency	**Terminal Points in the Curved Part**			**Failure Reasons**	
	N (%)	**Upper** **N (%)**	**Middle** **N (%)**	**Lower** **N (%)**	**Ledge Formation** **N (%)**	**iRoot SP Resistance** **N (%)**
PTR	10 (58.82)	3 (17.65)	4 (23.53)	0 (0)	5 (29.42)	2 (11.76)
WOG	11 (64.71)	6 (35.29)	0 (0)	0 (0)	2 (11.76)	4 (23.53)
RB	14 (82.35)	0 (0)	1 (5.88)	2 (11.76)	1 (5.88)	2 (11.76)
P value	0.287	0.023*	0.111	0.320	0.150	0.568

*Significant difference at the 5.0 % level

Table 2 summarizes the initial root filling volume and reduction of filling materials. No significant difference in total reduction of filling material was observed ($P > 0.05$), only the apical third of the RB group presented significantly greater reduction than WOG group ($P < 0.05$).

Table 2
Initial root filling volume and volume reduction of filling materials

	PTR Mean ± SD	WOG Mean ± SD	RB Mean ± SD
Initial Filling Volume (mm^3)			
Cervical	3.80 ± 0.57^{a}	3.24 ± 0.49^{a}	3.36 ± 0.79^{a}
Middle	1.85 ± 0.37^{a}	1.45 ± 0.43^{a}	1.32 ± 0.37^{a}
Apical	0.53 ± 0.14^{a}	0.52 ± 0.20^{a}	0.41 ± 0.20^{a}
Total	6.17 ± 0.99^{b}	5.22 ± 0.90^{a}	5.09 ± 1.11^{a}
Reduction in Filling Material (%)			
Cervical	98.89 ± 1.92^{A}	94.95 ± 5.04^{A}	97.06 ± 5.47^{A}
Middle	90.22 ± 9.12^{A}	91.56 ± 5.32^{A}	93.03 ± 10.23^{A}
Apical	52.82 ± 20.28^{abB}	45.50 ± 17.76^{bB}	56.95 ± 12.12^{aB}
Total	92.40 ± 3.68^{A}	88.23 ± 6.61^{A}	92.62 ± 4.81^{A}

Lowercase letters represent statistical differences in row ($P < 0.05$). Uppercase letters represent statistical differences in column considering total root canal length (total) and each third individually (cervical, middle, and apical) ($P < 0.05$)

Table 3 shows the results of dentinal microcracks evaluation. New dentinal microcracks were observed in all the three groups after retreatment from the cross-sectional images (Fig. 2). The percent of increasing dentinal microcrack were 0.44% (n = 66) in PTR group, 0.20% (n = 35) in WOG group, and 0.28% (n = 51) in RB group, respectively. Meanwhile, the incidence of microcrack in PTR group was higher than that in other groups ($P < 0.05$).

Table 3
Numbers and percent of cross-sectional images with dentinal microcracks before and after retreatment

	PTR N (%)	WOG N (%)	RB N (%)	*P* value
Before Retreatment	102(0.67)	108 (0.62)	106 (0.58)	0.581
After Retreatment	168(1.11)	143 (0.82)	157(0.86)	0.015*

*Significant difference at the 5.0 % level

Discussion

The performance of PTR, WOG, and RB systems in removing iRoot SP and GP from curved root canals was compared for the first time, and the portions of the curved part of root canal were defined, thereby analyzing the ability of three approaches to negotiate the curved part and the reasons for blockage. Meanwhile, a resolution higher than in previous studies, that is 12.8–19.9μm, was applied to observe the occurrence of complications like the formation of ledge and microcrack [13, 14, 25]. Three types of instruments, belonging to rotary system and reciprocating system, were applied in this study. The result suggested that RB had superior ability to negotiate the upper portion smoothly and obtained more reduction at apical third than other groups, and there formed more dentinal microcracks in PTR group in this study. However, no significant differences were observed among groups in filling material reduction, ledge formation, and iRoot SP resistance.

Most studies presented that the straight and curved root canals obturated with AH plus regained satisfied patency post retreatment by using mechanical Ni-Ti instruments [11, 12, 14, 17]. The WL of most straight root canals obturated with bioceramic sealer EndoSequence BC could be regained, and the apical patency reached 80%-100% during retreatment [10, 25]. Our results revealed that the straight part of canals could be negotiated smoothly by all three approaches, but the curved part existed blockage and made it difficult to reestablish the patency. Meanwhile, 58.82% (PTR), 64.71% (WOG), and 82.35% (RB) of the samples in each group reestablish canal patency successfully. The discrepancy may be attributed to different design concept of these instruments and high strength of iRoot SP which resulted in blockage of the curved part and loss of patency in some samples [10].

The etiology of canal blockage includes calcification, instruments separation, or ledge formation. This study indicated that the portion which cannot be negotiated was located in the curved part through micro-CT scan images, and the probable reasons included ledge formation and iRoot SP resistance encountered by instruments. However, no statistical differences were found among groups. The iRoot SP resistance could be related to the direct contact between iRoot SP and the file tips, which have no cutting ability in all three approached. The higher-hardness iRoot SP obturated in the irregularly shaped area of the curved root canal increased the difficulty to negotiate [10]. Blockage caused by ledges impeded the instrument to travel along the direction of original canals to reach ideal WL [26]. The extreme flexibility and rebound tendency of Ni-Ti instruments caused a bypass to become difficult. Our result suggested that canals in RB group were negotiated more compared with other groups in the upper component. This finding was consistent with that of Romeiro1 et al [25]. It proved that RB possesses more excellent ability of exploration, and effectively follows the root canal path to reach apex.

Almost all studies presented that the reduction rate in the apical third of each group is significantly lower than that in the middle and cervical thirds [14, 25, 27]. This result is consistent with our conclusion. Material reduction rate, as an indirect indicator of patency regaining, is related to the cross-sectional design, taper, tip diameter, and movement mode of the instrument, which reflects retreatment efficiency [16, 27]. Our study presented that no statistical difference was found in the total reduction among three groups, and the apical third in the RB group was higher than that of others probably due to its S-shaped cross-sectional design that results in sharp cutting edges and larger chip space [28]. In addition, compared to two Ni-Ti systems (0.07 in WOG25 and 0.06 in PTN X2), the greater taper size at the tip of the RB system (0.08 in RB25) could contribute to this reduction of filling materials [16] .

The formation of dentinal microcracks occurred typically during the process of root canal shaping, cleaning, filling and retreatment [15, 29, 30]. Studies revealed that dentinal microcracks formed when using PTR and RB during root canal retreatment [15, 31], but limited evidence presented this phenomenon in WOG. At present, the formation and increased rate of new dentinal microcrack during retreatment procedure are still controversial [15, 32, 33]. Our results displayed that all three approaches produced microcracks in the root wall, which could be relevant to the increased heat production during retreatment due to the high-strength of iRoot SP and strong bond between iRoot SP and dentine. At the same time, the higher resolution of micro-CT scanning brought more detective numbers than that of previous studies. The increasing dentinal microcracks in PTR was more than that in other groups, this may be related to the continuous rotational force and constant torque applied by the PTR rotary system on the root canal walls, and the lower flexibility of PTR than other two systems [34, 35]. However, additional studies are necessary to evaluate the changes in original microcracks morphology from cross-sectional images after retreatment.

Conclusion

All three tested Ni-Ti instruments showed the similar retreatability of curved root canals obturated with gutta-percha and iRoot SP. RB system may be more effective and safer in curved root canal retreatment.

Abbreviations

micro-CT
micro-computed tomographic; GP:gutta-percha; Ni-Ti:Nickel-titanium; PTR:ProTaper Universal Retreatment; WOG:Waveone Gold; RB:Reciproc Blue

Declarations

Acknowledgements

The authors deny any conflicts of interest related to this study.

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Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Authors' contributions

YC, LSW and FQ participated in the laboratory phase, selecting and preparing the samples. MYS and RL performed the micro-CT analysis and statistical analysis of the data. YC, WPT and KHQ discussed the findings and drafted the article. All authors read and approved the final manuscript.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Ethics approval and consent to participate

The present protocol was approved by the Ethics Committee of the Hospital of Stomatology, Tianjin Medical University, Tianjin, China (no. TMUhMEC2020115). We have obtained informed consent from all the participants, all procedures performed in the present study, involving human participants, were in accordance with the ethical standards of the institutional and/or national research committee.

Author details

[1] Department of Endodontics, College of Stomatology, Tianjin Medical University, Tianjin, China. [2] Research Center of Basic Medical Sciences, Tianjin Medical University, Tianjin, China.

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Figures

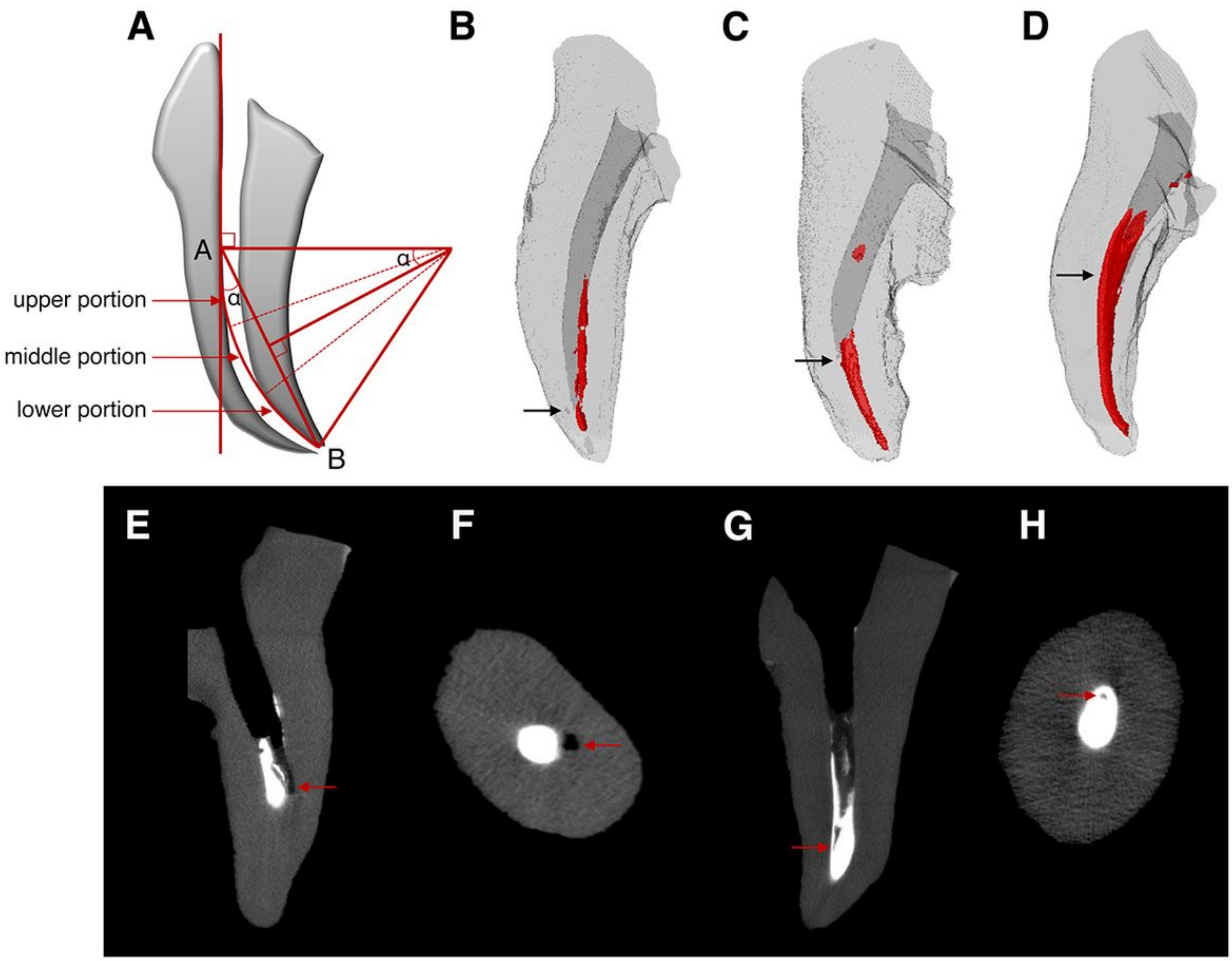

Figure 1

Representative samples that show blockage positions at three different curved portions (colored according to the volume of material under investigation), ledge formation and iRoot SP resistance. (A) Schematic diagram of three portions (upper, middle and lower) of the curved part; blockage at (B) lower,

(C) middle, and (D) upper portion; (E) Coronal axes micro-CT scan image and (F) Transaxial axes micro-CT scan image of ledge formation; (G) Coronal axes micro-CT scan image and (H) Transaxial axes micro-CT scan image of iRoot SP resistance. The arrows (red) in (B-D) indicate the blockage position, (E, F) indicate ledge formation, and (G, H) indicate iRoot SP resistance encountering.

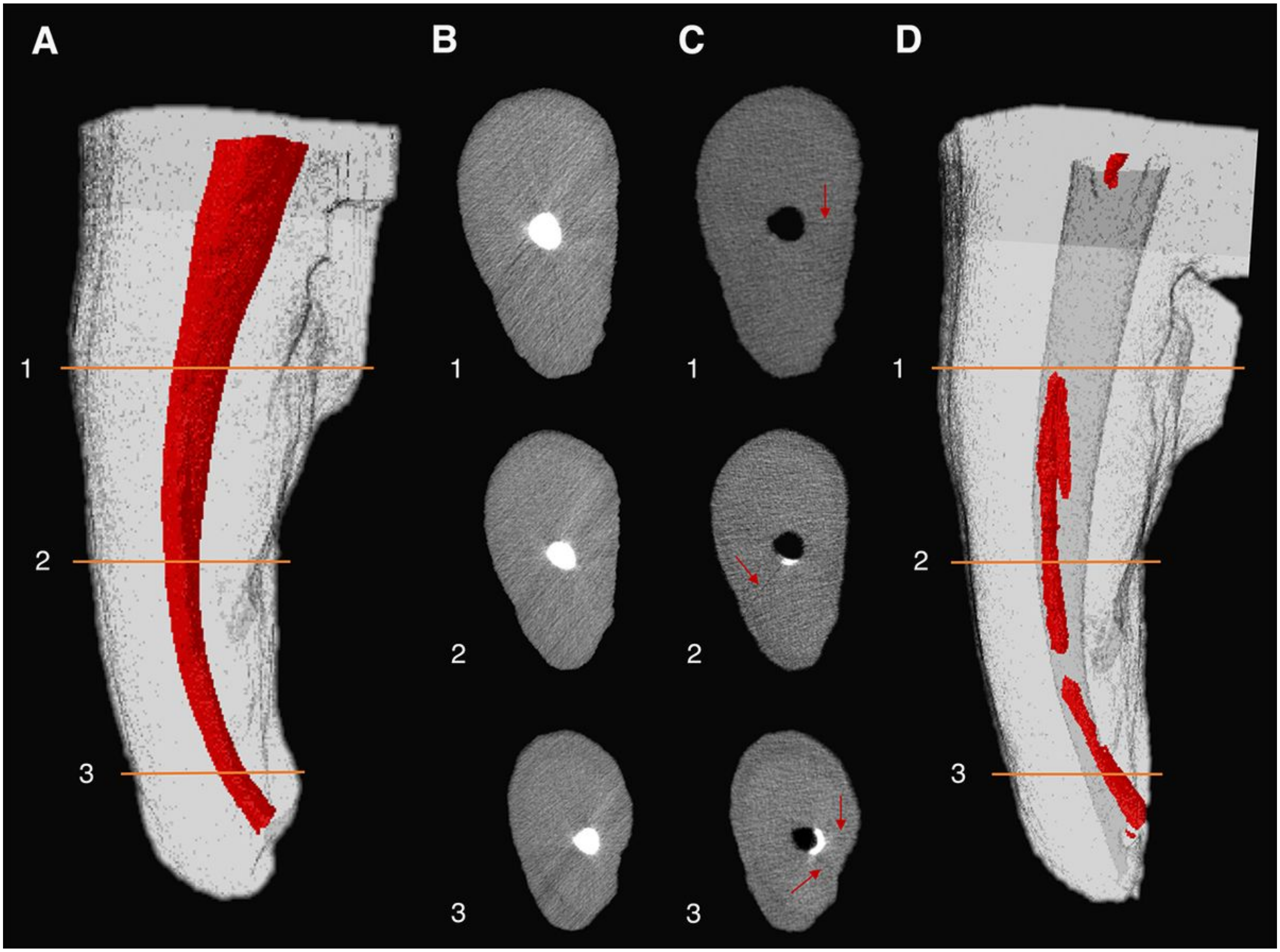

Figure 2

Representative sample that show microcrack formation. A representative 3D reconstructed model (A) pre- and (D) post-retreatment; Three representative cross-sectional slices of cervical, middle and apical thirds (B) pre- and (C) post-retreatment. The arrows (red) indicate dentinal microcrack in the cross-section images, and the regions are indicated with the lines (orange).