Original Article

ProTaper Universal Retreatment Retreatment Potential in Oval-Shaped Canals Filled with Different Obturation Techniques—A Micro-Computed Tomography Study

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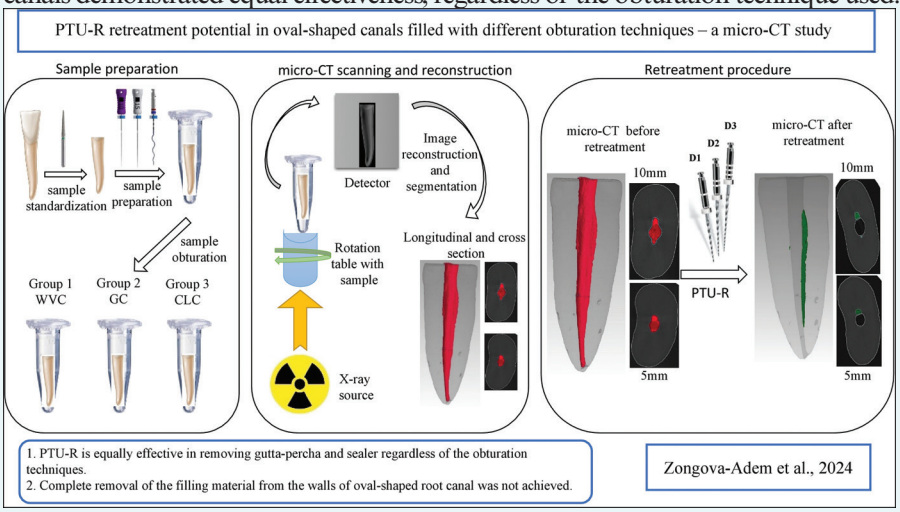
ABSTRACT

Aim: The objective of this *in vitro* micro-computed tomography investigation is to assess the efficacy of the ProTaper Universal Retreatment System in retreating oval-shaped root canals filled with three obturation procedures. **Materials and Methods:** Thirty-six lower incisors with a single oval root canal were prepared using XP-Endo Shaper up to size 30/0.04, and allocated into three equal groups based on the filling technique: Group 1: Warm vertical condensation technique; Group 2: GuttaCore obturators; Group 3: Cold lateral condensation technique. All samples were further retreated using the ProTaper Universal Retreatment system. Micro-CT analysis was performed before and after the retreatment procedure. Statistical analysis was performed with a significance level of 0.05. Data analysis was conducted using the Kolmogorov-Smirnov and Kruskal–Wallis H tests. **Results:** The best performance of the files was achieved when the removal of the filling in the entire canal was considered. However, this outcome was not statistically significant when compared with the other observed root canal levels. The retreatment procedure could not ensure thorough cleanliness of the canal walls from filling remnants, regardless of the obturation technique and observational level. **Conclusions:** The ProTaper Universal Retreatment system used for the removal of gutta-percha and sealer in oval-shaped root canals demonstrated equal effectiveness, regardless of the obturation technique used.

GRAPHICAL ABSTRACT



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Introduction

The effectiveness of an initial endodontic procedure is determined by precise shaping, disinfection, and filling of the endodontic space, as well as by hermetic sealing of the restored tooth. Adequate endodontic and restorative treatment are prerequisites for a favorable treatment outcome.[1,2]

The presence of anatomical difficulties, that is, recesses, isthmuses, ramifications, and the root canal shape, could hinder the mechanical and chemical debridement and influence the long-term prognosis of the treated tooth.[3]

The endodontic success is strongly dependent on the three-dimensional hermetic sealing of canal space.[4] Many obturation techniques have been developed and have been used over time. Although the cold lateral condensation (CLC) technique is considered a gold standard, the excessive amount of sealer and the questionable homogeneity of the filling are considered disadvantageous.[5] Sealers are known to shrink or dissolve over time, thus making these areas predisposed to bacterial invasion.[6] Thermoplastic filling techniques, such as warm vertical condensation (WVC) and carrier-based techniques, use a very small amount of a sealer.[7] They have been advocated to achieve better adherence of the gutta-percha to the walls of the canals, obtaining a canal filling with a lower incidence of voids compared to the CLC technique.[5,8] However, the better sealing capability of the aforementioned filling techniques could negatively influence the efficiency of the retreatment endodontic instruments, especially in root canals with more complex or oval anatomy.[9]

Nonsurgical endodontic retreatment is considered one of the major options for resolving cases with persistent periapical lesions or secondary bacterial infections.

Various retreatment protocols have been introduced. Despite the variety of instruments, devices, and solutions used,[10,11] many studies have concluded that no single method can effectively remove all filling materials from the root canal walls.[12] The procedure is particularly challenging when retreating teeth have complex root canal morphology or oval-shaped root canals.[13–15] Additionally, the type of obturation technique may influence the effectiveness of the endodontic instruments in the retreatment process.[16]

Endodontic retreatment with rotary instruments is a widely and profoundly investigated topic over the past 20 years.[17–20] The ProTaper Universal Retreatment System (PTU-R) (Dentsply Sirona Endodontics) is one of the most commonly utilized NiTi retreatment systems.[21–24] Nonetheless, very few authors focus on its potential to remove root canal filling material from oval-shaped canals of the smallest teeth in the human permanent dentition, that is, lower incisors.[25,26] Their canals are often oval-shaped with a greater buccolingual diameter, which hinders the cleaning of the obturation material.

The aim of this study is to assess the efficiency of the PTU-R system for retreating oval-shaped root canals that have been filled using three obturation techniques. The null hypothesis developed is that the studied filling techniques affect the retreatment procedures in the same way.

Materials and Methods

Sample selection and experimental design

This research examined 36 straight, single-rooted mandibular incisors (curvature <5°),[27] with an entirely developed apex and no signs of external or internal resorption. The samples were selected from a pool of freshly extracted teeth. The extractions were unrelated to the current study, and the patients had provided written informed consent before the procedure. The teeth were removed and soaked for an hour in a 0.1% thymol solution. Thereafter, plaque and calculus were removed by using an ultrasonic scaler, and the surfaces were polished with discs, brushes, and polishing paste. Each tooth was digitally radiographed in both buccolingual and mesio-distal projections to confirm the existence of a single oval-shaped root canal (buccolingual to mesio-distal ratio 2:1) [Figure 1]. During the course of the experiment, the incisors were stored in 5 mL Eppendorf safe-lock tubes (FL Medical, Padova, Italy), filled with saline (0.9% NaCl) at ambient temperature.

Sample preparation

All sample teeth were decoronated using a green-coded diamond bur at a 16-mm root length. Root

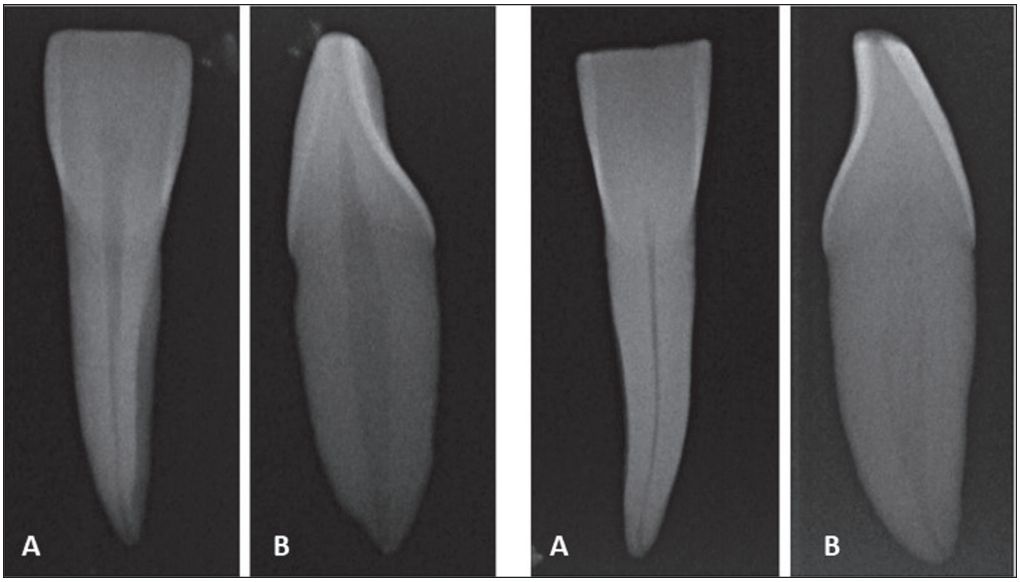

Figure 1: Inclusion criteria for the existence of oval canals verified by two-dimensional radiographs in different planes. (A = frontal plane; B = sagittal plane).

canal patency was achieved using an ISO size 10 K-file (Dentsply Sirona, Ballaigues, Switzerland) by inserting it into each root canal until the tip of the file was barely visible at the apical foramen. The working length (WL) was 1 mm shorter than the initial length. A smooth path was established using ISO size 10 and ISO size 15 K-files (Dentsply Sirona, Ballaigues, Switzerland). The shaping of each sample tooth was performed using the XP-Endo Shaper NiTi system (FKG Dentaire SA, La Chaux-de-Fonds, Switzerland) up to a size of 30/0.04 using an endodontic motor X Smart Plus (Dentsply Maillefer), at a speed of 800 rpm and torque of 1 Ncm. Glyde (Dentsply Sirona Endodontics, Ballaigues, Switzerland) was used for the instrumentation. Each NiTi instrument was used in a slow pecking motion until it reached 0.5 mm of the premeasured WL. Only three canals were shaped using a single file. NaOCl (CHLORAXID 2%, Cerkamed, Stalowa Wola, Poland) was used as an irrigant throughout all shaping procedures. A final rinse with 2% NaOCl and 17% EDTA (Cerkamed, Stalowa Wola, Poland) for 1 min was performed for each root canal after instrumentation was completed.

Root canal filling

The sample teeth were equally distributed into three groups (n = 12) based on the obturation technique used to fill the root canals, as follows:

- ***Group 1***—WVC technique

The canals were dried with Dia-Pro ISO.04 (DiaDent Europe B.V., Almere, The Netherlands) paper points and filled with gutta-percha cones ISO 30.04 (Dentsply Sirona Endodontics, Ballaigues, Switzerland) and AH Plus sealer (Dentsply Sirona Endodontics, Ballaigues, Switzerland) using the WVC technique with the AXIS Sybron's cordless elements free obturation system (SybronEndo/Kerr Endodontics, Orange, CA).[28] A Buchanan heat plugger was adjusted to fit in the root canal 5 mm shorter than the full WL. A gutta-percha cone of ISO size 30/.04, coated with AH Plus sealer, was seated with a tug back at full WL, and the coronal excess was cut at the orifice level. The plugger was then activated and steadily inserted into the canal at the adjusted depth, which was maintained steady for 5–10 s. After a few seconds of cooling, it was activated again for one second and then retrieved from the canal together with the excess gutta-percha. The remaining filling material was then downpacked using a Buchanan hand plugger. The remaining section of the canal was filled with warm gutta-percha material (backfill).

- ***Group 2***—GuttaCore (GC) obturators

The apical gauging of the root canal after instrumentation was evaluated using a GC-size verifier, following the manufacturer's instructions. Red Verifier ISO size 25.05 (Dentsply Sirona Endodontics, Ballaigues, Switzerland) was passively placed into the canal until it reached full WL, and a matching red GC obturator ISO 25.04 was selected for each sample. After drying the root canals, AH Plus sealer was applied using Dia-Pro ISO.04 paper points (DiaDent Europe B.V., Almere, The Netherlands) in a very thin layer. The GC obturators, adjusted for size (20–25), were thermoplastizied by using the Thermaprep 2 Oven (Dentsply Sirona Endodontics, Ballaigues, Switzerland). The heated obturator was

inserted smoothly for approximately 6 s, until the WL was reached. After 8–10 s of cooling, the shaft of the obturator was removed by back-and-forth movement until breakage.

- ***Group 3***—CLC technique

An adjusted gutta-percha cone ISO size 30.04, covered with an AH Plus sealer, was inserted into the root canal to the initially defined WL. Finger Spreder ISO 25 (Dentsply Sirona Endodontics, Ballaigues, Switzerland) was placed adjacent to the gutta-percha cone at a distance of 1–2 mm from the WL. The master cone was laterally condensed by utilizing counterclockwise rotations of the finger spreader. The root canal was filled sequentially by placing additional gutta-percha cones of ISO sizes 25/0.02, 20/0.02, and 15/0.02 (Dentsply Sirona Endodontics, Ballaigues, Switzerland), and each of them was condensed laterally next to the previous cones. Excess gutta-percha was trimmed with a hot instrument.

After completing the obturation procedure, all samples were sealed temporarily using Citodur Hard (DoriDent, Wien, Austria) and stored at 100% humidity for 1 month to allow the sealer to fully set.[29]

Obturation quality was evaluated using digital radiographs and micro-computed tomography (micro-CT) analysis. Scanning was performed using a Nikon XT H 225 (Nikon Metrology, Tring, UK) operated at a voltage of 100 kV, a current of 125 μA, a 1.0-mm-thick aluminum filter, 500 ms exposure time, 2880 projections, and 1 frame per projection. The VG Studio MAX version 2.2 (Volume Graphics, Heidelberg, Germany) software was used for a cross-sectional scan of each sample at distances of 5 and 10 mm from the apex. Samples with insufficient filling were replaced with new ones.

Volumetric analysis of the filling material in the sections of 5 mm, 10 mm, and the whole root canal space was performed using Fiji software v.1.54f (Rasband W.S., National Institutes of Health, Bethesda, Maryland). The scans were segmented into features of interest (filling material) and background using the "Threshold" tool set to "Minimum." The volume of the filling material was calculated in mm^3 for each segment and specimen.

An experienced operator who was blinded to the obturation technique performed the secondary treatment procedure. All samples were retreated using PTU-R, without the presence of solvents, in the following sequence: D1 (30.09), D2 (25.08), and D3 (20.07) from each third of the root canal.

The instruments were operated in a continuous rotation motion and crown-down manner at a speed of 500 rpm and a torque of 2.5 Ncm, following the manufacturer's recommendations. Each instrument was used to retreat a total of three canals. After the instrumentation with each file, the samples were thoroughly rinsed with 2% NaOCl. The retreatment technique was finalized when the entire WL was achieved, the canal walls were clear of debris, and no filling material was detected on the surface of the files.

The samples were dried using paper points, and a second micro-CT analysis was performed. Volumetric analysis of the residual filling material was performed again for each segment and specimen by employing the aforementioned methodology. The quantity of the removed filling material was measured as a percentage and subjected to further statistical analysis.

All micro-CT scans, measurements, data analysis, and visual reconstructions were performed by an experienced examiner who was blinded to the endodontic protocol used for each sample.

Statistical analysis

IBM SPSS Statistics 23.0 software (International Business Machines Corporation, New York, NY) was used for statistical analysis. The quantity of removed root canal filling substance was measured as a percentage (%), along with the respective averages and standard deviations. The Kolmogorov-Smirnov test showed a non-normal distribution of the data and a limited sample size, which is why an independent sample comparison was conducted using the Kruskal–Wallis H test. The confidence level was set at 95% with a significance level (P) of 0.05.

Results

The volume of the root canal filling was measured at three specific levels—5 and 10 mm from the apex and at full canal length before and after the retreatment procedure with PTU-R. Despite the obturation technique and the observational level, the retreatment procedure did not achieve complete cleanliness of the canal walls [Table 1 and Table 2]. No endodontic mishaps or errors were encountered during the course of the study. Figure 2 displays the micro-CT scans of typical samples and their 5-mm and 10-mm cross-sectional scans before and after the retreatment procedure with PTU-R [Figure 2].

The quantity of the obturation material removed was measured as a percentage. Upon comparing the removal of the root canal filling at the entire length of the canal for all experimental groups to the initial values recorded after root canal obturation, it was found to

Table 1: Intergroup comparison of the percentage of removed root canal filling material after retreatment with PTU-R system at the three tested root canal portions

Observational level	Obturation technique	*N*	% of removed root canal filling			
			Min	Max	Mean ± SD	*P* value
5 mm	WVC	12	2,17	91,36	58,77 ± 28,19	0,643
	GC	12	7,32	96,59	69,32 ± 27,47	
	CLC	12	17,60	99,84	63,35 ± 32,10	
10 mm	WVC	12	20,95	97,42	72,58 ± 23,32	0,739
	GC	12	30,38	98,75	72,55 ± 23,94	
	CLC	12	20,76	97,48	79,05 ± 20,97	
Full	WVC	12	65,81	97,33	88,16 ± 9,11	0,930
	GC	12	65,49	99,45	88,06 ± 10,98	
	CLC	12	61,955	98,956	88,78 ± 10,15	

*WVC = warm vertical condensation, GC = GuttaCore, CLC = cold lateral condensation

Table 2: Intragroup comparison of the percentage of removed root canal filling material after retreatment with PTU-R system at the three tested root canal portions

Obturation technique	Observational level	*N*	% of removed root canal filling			
			Min	Max	Mean ± SD	*P* value
WVC	5	12	2,17	91,36	58,77 ± 28,19	0,010
	10	12	20,95	97,42	72,58 ± 23,32	
	Full	12	65,81	97,33	88,16 ± 9,11	
GC	5	12	7,32	96,59	69,32 ± 27,47	0,075
	10	12	30,38	98,75	72,55 ± 23,94	
	Full	12	65,49	99,45	88,06 ± 10,98	
CLC	5	12	17,60	99,84	63,35 ± 32,10	0,163
	10	12	20,76	97,48	79,05 ± 20,97	
	Full	12	61,955	98,956	88,78 ± 10,15	

*WVC = warm vertical condensation, GC = GuttaCore, CLC = cold lateral condensation

be the most significant. However, this outcome did not differ statistically from the rest of the observational levels of the root canal [Table 1]. Regardless, in the 10 mm segments, the retreatment system achieved better results than the apical portion of the root canal, although the differences among the three obturation techniques were still statistically insignificant ($P = 0.739$; GC group—72,55 ± 23,94; WVC group—72,58 ± 23,32; CLC group—79,05 ± 20,97).

Table 2 illustrates the percentage of filling material removed by the PTU-R at the three observed levels. The highest amount of material was removed at full canal length in all three techniques. Statistically, there was no significant variation in the amount of material removed at different root levels within each group. Nevertheless, in the WVC group, significantly less filling was removed by the retreatment system at the 5 mm segment than that registered at the full canal length (Kruskal–Wallis Test, $\chi^2(2) = 9248$, $P = 0.010$).

Discussion

To the best of our knowledge, there are few articles discussing the sole efficiency of PTU-R in the retreatment of lower incisors by means of micro-CT.[25,26] Moreover, none of them have compared the retreatment potential of the tested system for the most commonly used obturation techniques—CLC, WVC, and GC. Since CLC, WVC, and GC are well-known and performed by dentists worldwide, we have found it suitable to inspect if the filling technique defines the performance of the PTU-R and to what extent.

The tested retreatment system managed to remove the obturation material from the root canal walls of all specimens, thus supporting the null hypothesis. Despite its evident potential for retreatment, the NiTi system was unable to thoroughly clean the root canal walls of the filling residue in any specimens. This observation aligns with previous micro-CT studies that have examined the effectiveness of various retreatment protocols.[30]

Removal of the obturation material from the apical third of the canal is considered the most critical part of the secondary treatment procedure.[31,32] This study found an insignificant difference between the experimental groups when comparing the 5 mm level of the samples. Slightly less filling material was removed

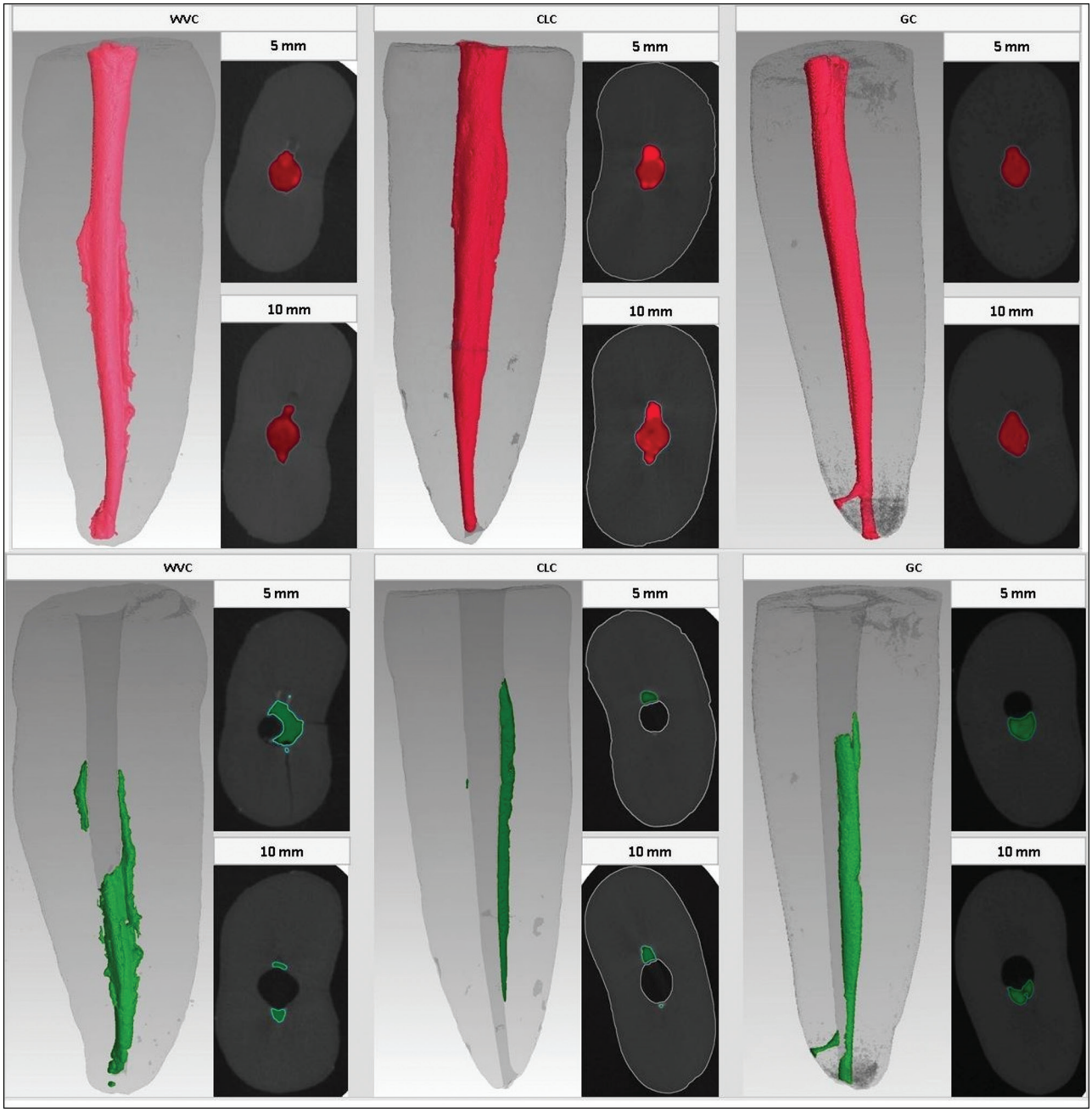

Figure 2: Representative samples of reconstructed 3D micro-CT images from each group and their 5-mm and 10-mm cross-sections, showing the filling materials after obturation in red color and the remaining filling material after retreatment with PTU-R in green color. *WVC = warm vertical condensation, GC = GuttaCore, CLC = cold lateral condensation

from the WVC specimens, which might be ascribed to the technique itself.[8,33] Because WVC resulted in a greater percentage of gutta-perch-filled areas and fewer voids inside the filling, a larger amount of untouched thermoplasticized gutta-percha was expected.

Reports in the literature lack consensus on sample selection for micro-CT investigations in endodontic retreatment cases. In the current study, we selected oval-shaped root canals of mandibular incisors with similar anatomical characteristics. Our decision was influenced by the high prevalence of such root canal configurations previously reported by other authors.[34,35] This root canal anatomy presents a real challenge for endodontists. The specific cross-sectional morphology does not corroborate the circular preparation provided by the commonly used engine-driven nickel-titanium (NiTi) endodontic instruments. Large areas of the distant ends of the oval canal walls are left untouched and can act as reservoirs for debris and bacteria, which may lead to future endodontic failure.[36]

Various techniques and methodologies have been employed to evaluate the amount of filling material left following retreatment, such as specimen sectioning, two-dimensional radiographs, stereomicroscope images, scanning electron microscopy (SEM) and environmental scanning electron microscopy analysis, energy dispersive X-ray spectroscopy (EDX) and micro-CT.[37] The efficiency of the NiTi system was determined using micro-CT. Given its accuracy and non-invasiveness, micro-CT imaging is the preferred tool for quantitative and qualitative analysis of endodontic procedures.[38,39] The quantity of successfully removed filling material was calculated as a percentage of the original volume of the canal filling material, as presented in previous studies.[12]

To avoid bias, all retreatment procedures were performed by one operator using the PTU-R system without solvents. This system has been well studied and proven to be efficient in removing filling material from canals filled with thermoplastic techniques.[30] The specifics of the NiTi system, including variable taper, large base core, continuously changing helical pitch, and convex triangular cross-section, increase the cutting efficiency of the files and allow coronal evacuation of gutta-percha from the root canal.[40,41] The instruments were used consecutively until the WL was reached, the canal walls were free of debris, and no filling material was observed on the file flutes. Although some authors recommend additional enlargement of the apical diameter for better cleaning of the apical third and the use of different solvents,[42] this was not done in the present study because we intended to investigate the impact of the NiTi retreatment system alone.

In summary, the current results confirm that the PTU-R system is efficient in removing root canal filling materials, as demonstrated in previous studies,[43] and its performance remains consistent across various obturation techniques. Nevertheless, it should be noted that the system did not achieve complete cleanliness of the canal surface, as concluded previously.[44]

Additional study is required to examine the performance of NiTi instruments specifically designed for retreatment purposes.

One potential limitation of the present study is that it only assessed the quantity of the removed root canal filling material without addressing the probable adverse effects that PTU-R might have caused to the root canal system, such as apical transportation and fracture resistance of the endodontically retreated teeth. Further investigations are needed to focus on the negative impact of the size and taper of the tested system on the biomechanical properties of the root canals. Similar to some previously published findings,[14] the sample size in our experiment was not determined by dedicated software, which might be considered as another limitation of the study.

Conclusions

Given the limitations of the present study, it can be concluded that PTU-R is equally efficient in removing both gutta-percha and sealer, regardless of the obturation technique. However, the filling material from the oval-shaped root canal walls was not entirely removed.

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Conflicts of interest

None.

Author contributions

EK and ST conceptualized the study design. SZ, IT, and VD performed the experiments. SZ performed the volumetric analysis and wrote the paper. IT, VD, and EK participated in the statistical data interpretation. All authors approved the final manuscript.

Ethical policy and institutional review board statement

The experiment was approved by the Research Ethics Committee of the Medical University Sofia, Sofia, Bulgaria, with protocol No. 907/22.03.2022.

Patient declaration of consent

Not applicable.

Data availability statement

Data are available upon request.

List of Abbreviations

CLC: Cold lateral condensation
WVC: Warm vertical condensation
PTU-R: ProTaper universal retreatment
ISO: International Organization for Standardization
WL: Working length
NaOCl: Sodium hypochlorite
EDTA: Ethylenediaminetetraacetic acid
GC: GuttaCore

Micro-CT: Micro-computed tomography
NiTi: Nickel-titanium
SEM: Scanning electron microscopy
ESEM: Environmental scanning electron microscopy
EDX: Energy dispersive X-ray spectroscopy

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