ORIGINAL ARTICLE

Turk Endod J 2026;11(1):85–92
doi: 10.14744/TEJ.2025.86548

An in vitro comparison of the retreatment efficacy of different root canal sealers and solvents

Evren Sariyilmaz,[1] Koray Misirci[2]

[1]Department of Endodontics, Çanakkale Onsekiz Mart University Faculty of Dentistry, Canakkale, Türkiye
[2]Private Giresun Oral and Dental Health Clinic, Giresun, Türkiye

Purpose: The aim of this study was to compare the effectiveness of different root canal filling solvents in removing filling material with AH Plus or MTA-Fillapex from premolar teeth with artificially created lateral canals.

Methods: One hundred twenty extracted single-rooted premolar teeth with standardized artificial lateral canals were prepared and obturated using AH Plus or MTA-Fillapex with a warm vertical compaction technique. Retreatment was performed using ProTaper Universal Retreatment instruments with four different conditions: No solvent (control), chloroform, endosolv, and eucalyptol solvent. Residual filling material in the main canals was evaluated under a stereomicroscope using pixel-based image analysis, while residual filling material in the lateral canals was assessed radiographically. Main canal data were analyzed using two-way ANOVA and post-hoc tests, whereas lateral canal data were reported descriptively.

Results: The type of sealer did not significantly affect the amount of residual filling material in the main canal. In contrast, the solvent type had a significant effect. Endosolv resulted in significantly less residual filling material compared with chloroform, eucaliptol, and the control group. In the lateral canals, no method provided measurable and consistent removal, and therefore only descriptive analysis was performed.

Conclusion: Endosolv was the most effective solvent for removing root canal filling materials from the main canal. However, the anatomical complexity of lateral canals limits the effectiveness of all retreatment procedures.

Keywords: Endodontic retreatment; lateral canal; root canal filling removal; solvents.

Introduction

The primary objective of endodontic retreatment is the complete removal of existing root canal filling materials, effective disinfection of the root canal system, and subsequent three-dimensional obturation (1). For successful retreatment, removing as much of the previous root canal filling as possible is essential to allow for the effective elimination of pathogenic microorganisms and necrotic tissue remnants (2,3). However, complete removal of the filling

Cite this article as: Sariyilmaz E, Misirci K. An in vitro comparison of the retreatment efficacy of different root canal sealers and solvents. Turk Endod J 2026;11:85-92.
Correspondence: Evren Sarıyılmaz . Department of Endodontics, Çanakkale Onsekiz Mart University Faculty of Dentistry, Canakkale, Türkiye
Tel: +90 532 – 707 87 23 e-mail: evrensariyilmaz@yahoo.com
Submitted: December 03, 2025 Revised: December 08, 2025 Accepted: December 09, 2025 Published: April 27, 2026

material is often challenging due to the complexity of root canal anatomy and the physicochemical properties of the materials used (4,5).

Within these complex anatomical structures, lateral canals and accessory pathways are defined as critical regions that significantly affect endodontic success (6,7). Although it has been reported that tissues within lateral canals and apical ramifications are not adequately affected by irrigation and instrumentation (8), it is frequently observed that these areas become filled by the mechanical extrusion of sealer or gutta-percha during obturation. Therefore, the dissolution of residual filling material at the entrances of lateral canals during retreatment is of considerable clinical importance.

Studies have demonstrated that the complete removal of root canal filling materials using current instruments and techniques during retreatment is not always achievable (5,9,10). Histological evaluations of teeth with apical periodontitis have revealed that bacteria may remain protected within residual filling materials (8). The use of solvents to facilitate the removal of gutta-percha and sealers during retreatment has been considered advantageous in some studies (11,12). Rossi-Fedele and Ahmed (13) reported that when solvents are used particularly at the initial stage of retreatment, they may increase file penetration into the root canal but may negatively affect cleaning efficacy; conversely, when applied after instrumentation, they may reduce the amount of remaining filling material. Nevertheless, there is no consensus regarding the use of solvents. Some investigations have shown that solvent application results in the formation of a softened gutta-percha layer on the canal walls, which may render the retreatment procedure more difficult and time-consuming (14,15). In the existing literature, the effects of gutta-percha solvents have mainly been evaluated within the main root canal (11,12,14,15) and the isthmus (5); however, evidence regarding their effectiveness in lateral canals remains very limited, particularly in canals filled with epoxy resin–based or MTA-based sealers.

The aim of this study was to evaluate the efficacy of different root canal filling solvents in removing AH Plus– and MTA-Fillapex–based fillings from the main canal and from artificially created lateral canals in premolar teeth obturated using thermoplasticized techniques, using radiographic and stereomicroscopic analyses.

The null hypotheses tested in this study were defined as follows:

H_{01}: The type of root canal sealer has no effect on the efficacy of sealer removal from the main root canal during retreatment performed with different solvents.

H_{02}: Different root canal filling solvents used during endodontic retreatment have no effect on the efficacy of removal of the previous root canal filling material from the main root canal.

H_{03}: Different root canal filling solvents used during endodontic retreatment have no effect on the efficacy of removal of the previous filling material from the lateral canals.

Materials and Methods

Ethical approval for this study was obtained from the Ordu University Clinical Research Ethics Committee (Decision No: 2020-07, Date: 16/01/2020) and it was conducted according to the Declaration of Helsinki.

The total number of samples required for the study was determined based on a data from the previous study (16) using the G*Power 3.1 software package (Heinrich Heine University, Dusseldorf, Germany). The minimum required total sample size was calculated as 120 (n:15) based on the F test family, an effect size of 0.4722424, an alpha-type error of 0.05, and power of 0.85.

A total of 120 single-rooted mandibular premolar teeth of similar size and dimensions, extracted for periodontal or prosthetic reasons, were used in this study. Teeth with straight roots, complete root development, and without caries, restorations, calcifications, or root resorption were included. Root curvature was assessed using the Schneider method, and only teeth exhibiting a curvature between 0° and 10° were selected. Soft tissue remnants and debris were removed from the root surfaces using periodontal curettes.

The crowns of the teeth were removed to standardize the working length to 15 mm. The working length was determined as 1 mm short of the apical foramen. Root canals were prepared up to a Reciproc Blue 40/.06 instrument (VDW, Munich, Germany) and irrigated with 2.5% NaOCl. Final irrigation was performed using 17% EDTA, distilled water, and 2.5% NaOCl, after which the canals were dried with paper points.

On the mesial and distal surfaces of the teeth, three simulated lateral canals were created at distances of 3, 6, and 9 mm from the apex using a #15 K-reamer (VDW, Munich, Germany) mounted on a low-speed handpiece operating at 20,000 rpm. According to the type of root canal sealer to be used (AH Plus or MTA-Fillapex), the teeth were randomly divided into two main groups, with 60 teeth in each group.

Root canal obturation of 60 teeth was performed using AH Plus (Dentsply/Maillefer, USA), while MTA-Fillapex (Angelus, Brazil) was used for the remaining 60 teeth. A continuous wave of condensation technique with heat was

used for obturation of all root canals. Apical filling was achieved by cutting a master cone coated with sealer using the Elements Free Obturation System (SybronEndo) and condensing it with hand pluggers (SybronEndo, Orange, CA, USA). For obturation of the middle and coronal thirds of the canals, thermoplasticized gutta-percha heated in a backfill device was used, and condensation was performed with hand pluggers at each stage.

All 120 obturated teeth were embedded in silicone blocks. To obtain standardized radiographs using the parallel technique, a phosphor plate holder was positioned relative to the X-ray tube. Radiographic images were acquired using identical exposure parameters (60 kVp, 7 mA, 0.1 s) from the same distance and at the same angle for all specimens. After radiographic evaluation of the root canal fillings, samples in which the lateral canals were inadequately filled were excluded and replaced with newly prepared specimens.

The teeth in each main group were further subdivided into four subgroups according to the type of solvent used (no solvent, chloroform, Endosolv, and eucalyptol).

Control Group (No Solvent): Only ProTaper Universal Retreatment files were used for the removal of root canal fillings. The D1 (30/.09) file was used in the coronal third, the D2 (25/.08) file in the middle third, and the D3 (20/.07) file in the apical third to remove the filling material. The files were mounted on a VDW Gold Reciproc endomotor (VDW, Munich, Germany) and operated at 500 rpm and 3 N·cm torque, in accordance with the manufacturer's instructions, using gentle apical pressure.

Chloroform Group: The retreatment files D1 (30/.09), D2 (25/.08), and D3 (20/.07) were used at 500 rpm and 3 N·cm torque according to the manufacturer's recommendations. After use of the D1 file in the coronal region, 0.2 mL of chloroform was applied for 2 minutes. The D2 file was then used in the middle third with the same application of 0.2 mL chloroform. The D3 retreatment file was used throughout the procedure to remove the filling material from the apical third of the root canal. A total volume of 0.4 mL chloroform was used for each tooth.

Endosolv Group: All procedures performed in the chloroform group were followed identically, using a total of 0.4 mL Endosolv (Septodont, Paris, France) instead of chloroform.

Eucalyptol Group: All procedures performed in the chloroform group were followed identically, using a total of 0.4 mL eucalyptol (Kalsin, Aktu Ticaret, İzmir, Türkiye) instead of chloroform.

In all groups, the root canals were irrigated with 2.5 mL of 2.5% NaOCl solution between each instrumentation step. Final apical preparation was performed using an R50 (50/.05) file (VDW). During the final irrigation protocol following preparation, the canals were sequentially irrigated with 5 mL of 17% EDTA to remove the smear layer, 2.5 mL of distilled water, and subsequently 5 mL of 2.5% NaOCl, after which the root canals were dried with paper points.

Radiographs of all 120 retreated teeth were obtained again using the parallel technique with the same exposure parameters as those used before retreatment. The post-retreatment radiographs were compared with the pre-retreatment images. The efficacy of the root canal filling solvents in the lateral canals was evaluated by calculating the ratio of the dissolved material to the total amount of material within the lateral canal using the pixel-counting method in Adobe Photoshop CS6 Extended (Mountain View, California, USA). To ensure assessor blinding, all radiographic and stereomicroscopic images were coded by KM after image acquisition, and the analyses were performed by ES in a blinded manner without access to group allocation.

Subsequently, longitudinal grooves were prepared on the buccal and lingual surfaces of the teeth using a steel separator, and the specimens were split into two halves with a cement spatula. Digital images of the sectioned surfaces were obtained at ×8 magnification using a stereomicroscope (Nikon SMZ25, Tokyo, Japan). These images were analyzed with Adobe Photoshop CS6 Extended (Mountain View, California, USA), and the ratio of the remaining gutta-percha area to the total canal wall area was calculated using the pixel-counting method. The blinded coding procedure described above was applied to these images to maintain assessor blinding during pixel-based measurements.

Statistical Analysis

Normal distribution of the data was confirmed using the Kolmogorov–Smirnov test, and the homogeneity of variances was assessed with the Levene test. Differences in the amount of residual filling material obtained using different root canal sealers and different root canal filling solvents were analyzed by two-way analysis of variance (Two-way ANOVA). Multiple comparisons between groups were performed using the Tukey HSD post hoc test. All statistical analyses were conducted at a 95% confidence level, and a p value of <0.05 was considered statistically significant. The two-way ANOVA and Tukey HSD post hoc tests were applied only to the main canal data. Because of the predominance of zero values in the lateral canal measurements, these data were summarized descriptively without inferential statistical testing.

Results

Descriptive statistics of the residual filling material according to the solvents used with different root canal sealers are presented in Table 1. The type of root canal sealer was found to have no statistically significant effect on the amount of residual filling material remaining in the main canal ($F=0.656$, $p=0.420$). In contrast, the type of root canal filling solvent had a statistically significant effect on the amount of residual filling material ($F=10.910$, $p<0.001$).

According to the multiple comparisons, the Endosolv group resulted in significantly less residual filling material than the chloroform, eucalyptol, and control groups ($p=0.002$, $p<0.001$, and $p=0.029$, respectively). In addition, the eucalyptol group exhibited a significantly greater amount of residual filling material compared with the control group ($p=0.030$). No statistically significant differences were observed between the chloroform and control groups ($p=0.816$) or between the chloroform and eucalyptol groups ($p=0.225$). The interaction between sealer type and solvent type was not statistically significant ($p=0.093$) (Table 2).

In the evaluation of the lateral canals, no change was observed in many specimens in either the solvent or the control groups. In the AH Plus groups, 95.6% of all lateral canals created on the mesial and distal surfaces of the coronal, middle, and apical root regions in the control group, 66.6% in the chloroform group, 60.0% in the Endosolv group, and 73.3% in the eucalyptol group showed no removal of root canal filling and were recorded as 0% removal. Similarly, in the MTA-Fillapex groups, 95.5%, 57.8%, 95.5%, and 91.1% of the lateral canals, respectively, exhibited 0% removal, indicating that no filling material could be eliminated from these lateral canals. Because of the lack of measurable removal from the lateral canals and the consequent predominance of zero values in the dataset, no statistically demonstrable differences could be evaluated; therefore, no inferential statistical analysis was performed for these data.

Discussion

In studies in which artificial lateral canals have been created, both extracted permanent teeth (17) and transparent resin blocks or plastic teeth have been used as experimental models (18-20). Although resin blocks have been reported to be advantageous in terms of providing specimen standardization and eliminating the influence of canal preparation procedures (20), it has also been reported that the acrylic surface characteristics, compared with dentin, may affect the flow properties of gutta-percha and root canal sealers (18,20). Therefore, in the present study, extracted human teeth were used to obtain results closer to clinical conditions, and single-rooted premolar teeth with straight canals and similar root lengths were preferred to ensure standardization.

It has been reported that either 0.1-mm cylindrical burs or #15 K-reamers are used to create artificial lateral canals in extracted natural teeth (19,21). The diameter of natural lateral canals has been reported to range between 26 and 200 µm, with most commonly observed values between 60 and 80 µm (22). In another study, it was observed that 80% of lateral canals corresponded to or were narrower

Table 1. Descriptive statistics of residual filling material in the main canal (%) according to solvent and sealer

Solvent	AH Plus (n=15)	MTA-Fillapex (n=15)	Total (n=30)
Control	20.03±10.48	21.74±7.32	20.89
Chloroform	20.46±12.26	25.81±11.75	23.13
Endosolv	16.78±9.38	10.59±7.36	13.69
Eucalyptol	25.56±10.25	30.52±9.19	28.04

Values are presented as mean ± standard deviation (SD).

Table 2. Estimated marginal means of residual filling material in the main canal (%) according to solvent type and Tukey HSD comparison

Solvent	n	Adjusted Mean ± SE	95% Confidence Interval
Control	20.03±10.48	21.74±7.32	20.89
Chloroform	20.46±12.26	25.8	28.04

Values are presented as adjusted (estimated marginal) means ± standard error (SE) derived from the two-way ANOVA model. Different letters indicate statistically significant differences among solvent groups according to the Tukey HSD test ($p<0.05$).

than the diameter of a #10 K-reamer, 10% corresponded to a #15 K-reamer, and 7% had diameters equivalent to #20–40 K-reamers, while only 3% were wider than a #40 K-reamer tip (23). In the present study, lateral canals were created on the mesial and distal surfaces of premolar teeth at 3, 6, and 9 mm from the apex using a #15 K-reamer, thereby simulating dimensions comparable to those of natural lateral canals (22,23).

It was confirmed that the type of root canal sealer had no statistically significant effect on the amount of residual filling material remaining in the main canal, and thus the first null hypothesis of the study was accepted. Omidi et al. (24) similarly reported no statistically significant difference in residual sealer volume between AH Plus and MTA-Fillapex after retreatment, in agreement with the findings of the present study. In contrast, another study using cone-beam computed tomography reported significantly less residual filling material in the MTA-Fillapex group compared with AH Plus (25). These discrepancies in the literature may be attributed to differences in the imaging methods used (CBCT vs. radiography), measurement techniques (volumetric analysis vs. pixel analysis), obturation protocols, and variations in root canal anatomy.

In the present study, Endosolv was found to be more effective than chloroform. In contrast, another study evaluating the effects of different solvents on MTA-Fillapex in terms of re-establishing apical patency reported that chloroform and Endosolv E were more effective, whereas Endosolv R was insufficient (26). This discrepancy between the findings may be attributed to the fact that, in the present study, the amount of residual filling material was directly evaluated using macroscopic measurements, whereas in the aforementioned study, solvent efficacy was indirectly assessed based on the re-establishment of apical patency. In addition, while the cited study used two different formulations—Endosolv R for resin-based sealers and Endosolv E for zinc oxide–eugenol–based sealers—the present study employed a single-bottle Endosolv formulation claimed to be effective on both types of sealers. This methodological difference may also account for the divergence in results.

In previous studies, Endosolv R, consists of a formamide- and phenethyl alcohol–based formulation developed for resin-based sealers, and Endosolv E, which consists of a tetrachloroethylene-based formulation, intended for zinc oxide–eugenol–based sealers, were evaluated separately, and Endosolv R was reported to exhibit limited efficacy, particularly in terms of main canal wall cleanliness (26-28,29). In contrast, the Endosolv used in the present study, which consists of an ethyl acetate and pentyl acetate formulation, represents a newer single-bottle formulation that has been proposed for use with both resin- and eugenol-based sealers (29), and it demonstrated superior retreatment efficacy compared with the other solvents tested. Therefore, it is plausible that the lack of effectiveness reported for Endosolv in earlier studies, which were conducted using older formulations with different chemical compositions (Endosolv E/R) (26-28.), may account for the discrepancies with the present findings. Furthermore, while previous studies assessed efficacy mainly in terms of apical patency and at a microscopic level, the present study quantified the residual filling material radiographically and stereomicroscopically, representing another important methodological difference that may have influenced the outcomes.

Schäfer et al. (30), in their study evaluating the solubility of root canal sealers with different compositions in organic solvents, reported that epoxy resin–based sealers exhibited greater solubility in chloroform than in eucalyptol oil. Similarly, Alzraikat et al. (31), who compared the solubility of AH Plus and MTA-Fillapex in chloroform and eucalyptol, demonstrated that chloroform was a more effective solvent than eucalyptol for all root canal sealers tested. In the same study, AH Plus was reported to exhibit greater solubility than MTA-Fillapex. Overall, eucalyptol was found to have weak dissolving efficacy, and particularly low solubility of MTA-Fillapex in eucalyptol was reported. In contrast, in the present study, no statistically significant difference was observed between AH Plus and MTA-Fillapex in terms of solubility-related removal efficacy. Considering that the aforementioned studies evaluated the solubility of sealers in their pure form within solvents, whereas the present study investigated the removal efficacy of obturated materials adapted to dentin walls under simulated clinical conditions, this discrepancy is likely to be methodological in origin. It can be stated that the solubility of a material in its pure form does not directly correspond to its intracanal removal efficacy under clinical simulation, and that the clinical performance of solvents cannot be reliably predicted solely on the basis of solubility tests.

Scelza et al. (12) reported that chloroform, orange oil, and eucalyptol exhibited statistically similar cleaning efficacy within dentinal tubules. In contrast, the present study demonstrated statistically significant macroscopic differences, particularly in favor of Endosolv. This inconsistency is likely attributable to the methodological difference in the evaluation scale (microscopic dentinal tubule level vs. macroscopic canal lumen level).

Campello et al. (5) evaluated the effect of solvent use on the removal of filling material from the isthmus region us-

ing micro-CT and reported that eucalyptol did not significantly reduce the residual filling volume at either the main canal or isthmus level. Similarly, in the present study, due to the narrow anatomical configuration of the lateral canals, no sufficiently measurable removal was achieved in either the solvent or control groups. Natural lateral canal diameters have been reported to range from 26 to 200 µm, most commonly around 60–80 µm (22). In the present study, simulated lateral canals were created using a #15 K-reamer, resulting in relatively wide artificial canals (≥150 µm). Notably, even under these conditions, solvent-assisted removal from lateral canals remained minimal, suggesting that the effectiveness of solvents in narrower natural lateral canals is likely to be even more limited. This finding indicates that lateral canals represent one of the most resistant microanatomical regions with respect to endodontic retreatment. From a clinical perspective, it should be considered that filling material largely remaining within lateral canals may serve as a potential reservoir for infection and may contribute to the persistence of periapical lesions.

In the present study, since the type of root canal sealer (AH Plus vs. MTA-Fillapex) had no significant effect on the amount of residual filling material in the main canal, the first null hypothesis (H_{01}) was accepted. In contrast, because the type of root canal filling solvent used had a statistically significant effect on the amount of residual filling material in the main canal, the second null hypothesis (H_{02}) was rejected. Regarding the third null hypothesis (H_{03}), none of the solvents produced a measurable or clinically relevant degree of filling removal from the lateral canals. Because of the predominance of zero values, no meaningful statistical comparison could be carried out, and H_{03} was interpreted in the context of these anatomical and methodological limitations rather than being formally rejected. These findings support the notion that lateral canals represent one of the most resistant microanatomical regions during retreatment, largely retaining their filling material regardless of the solvent used.

This study was conducted under in vitro conditions and therefore does not fully reflect the clinical situation. To ensure standardization, a single retreatment system and needle irrigation were used; thus, the findings may not be generalizable to other retreatment approaches or irrigation activation techniques, and future studies should evaluate their effects on lateral canal removal. In addition, only two sealers (AH Plus and MTA-Fillapex) were tested, although numerous root canal sealers with different chemical compositions are currently available; including a broader range of materials may provide a more comprehensive understanding of solvent performance. In the evaluation of lateral canals, the use of a sectioning method may damage the tooth and root structures and may lead to errors in visual assessment. For this reason, the lateral canals could not be evaluated by sectioning and were assessed only using two-dimensional radiography. However, overlap, superimposition, and limited image resolution may have influenced the accuracy of these measurements. Accordingly, further studies employing advanced three-dimensional imaging techniques such as micro-computed tomography and confocal microscopy are required to minimize these limitations and to enable a more detailed evaluation of lateral canals. Finally, as with many in vitro models, the lateral canals were simulated; although 3D printing can generate standardized canal geometries, currently available resin materials do not fully replicate the physical and chemical characteristics of dental tissues. Further methodological innovations that better approximate clinical conditions are therefore warranted.

Conclusion

In this study, the type of root canal sealer had no effect on the amount of residual filling material remaining in the main canal, whereas the type of solvent significantly influenced retreatment efficacy. Endosolv resulted in significantly less residual filling material compared with chloroform, eucalyptol, and the control group. However, in the lateral canals, no group achieved a sufficient level of filling material removal, indicating that these regions are highly resistant to endodontic retreatment and may act as potential reservoirs for persistent infection. Therefore, periapical lesions should be periodically evaluated after retreatment, and if the lesion persists, additional advanced treatment protocols, such as surgical approaches, may need to be considered.

Authorship Contributions: Concept: E.S., K.M.; Design: E.S., K.M.; Supervision: E.S.; Fundings: E.S.; Materials: K.M.; Data: K.M.; Analysis: E.S., K.M.; Literature Search: K.M.; Writing: E.S., K.M.; Critical Revision: E.S.

Use of AI for Writing Assistance: Not declared

Source of Funding: No funding was granted for this study.

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

Ethical Approval: Ethical approval for this study was obtained from the Ordu University Clinical Research Ethics Committee (Decision No: 2020-07, Date: 16/01/2020)

Informed consent: Not applicable

References

1. Sjögren U, Hägglund B, Sundqvist G, et al. Factors affecting the long-term results of endodontic treatment. J Endod

1990; 16(10): 498–504. [CrossRef]
2. Imura N, Kato AS, Hata GI, et al. A comparison of the relative efficacies of four hand and rotary instrumentation techniques during endodontic retreatment. Int Endod J 2000; 33(4): 361–6. [CrossRef]
3. Tandon J, Taneja S, Bhalla VK, et al. Evaluation of bacterial reduction at various stages of endodontic retreatment after use of different disinfection regimens: An in vivo study. Eur Endod J 2022; 7(3): 210–6. [CrossRef]
4. Keles A, Alcin H, Kamalak A, et al. Oval shaped canal retreatment with self-adjusting file: A micro computed tomography study. Clin Oral Investig 2014; 18: 1147–53. [CrossRef]
5. Campello AF, Almeida BM, Franzoni MA, et al. Influence of solvent and a supplementary step with a finishing instrument on filling material removal from canals connected by an isthmus. Int Endod J 2019; 52(5): 716–24. [CrossRef]
6. Kumaran K, Ramesh S, Santhanam A. Lateral canals and its significance in endodontics. Int J Pharm Res 2020; 12: 1630–5. [CrossRef]
7. Ricucci D, Loghin S, Siqueira JF Jr. Exuberant Biofilm infection in a lateral canal as the cause of short-term endodontic treatment failure: Report of a case. J Endod 2013; 39(5): 712–8. [CrossRef]
8. Ricucci D, Siqueira JF Jr. Fate of the tissue in lateral canals and apical ramifications in response to pathologic conditions and treatment procedures. J Endod 2010; 36(1): 1–15. [CrossRef]
9. Kfir A, Tsesis I, Yakirevich E, et al. The efficacy of five techniques for removing root filling material: Microscopic versus radiographic evaluation. Int Endod J 2012; 45(1): 35–41. [CrossRef]
10. Silveira SB, Alves FRF, Marceliano-Alves MF, et al. Removal of root canal fillings in curved canals using either mani GPR or HyFlex NT followed by passive ultrasonic irrigation. J Endod 2018; 44(2): 299–303.e1. [CrossRef]
11. Sharma Y, Kumar SP, Girish GA, et al. Comparative evaluation of solubility of gutta-percha in three different solvents: A cone-beam computed tomography (CBCT) study. Cureus 2022; 14(7): e26788. [CrossRef]
12. Scelza MF, Coil JM, Maciel AC, et al. Comparative SEM evaluation of three solvents used in endodontic retreatment: An ex vivo study. J Appl Oral Sci 2008; 16(1): 24–9. [CrossRef]
13. Rossi-Fedele G, Ahmed HM. assessment of root canal filling removal effectiveness using micro-computed tomography: A systematic review. J Endod 2017; 43(4): 520–6. [CrossRef]
14. Takahashi CM, Cunha RS, de Martin AS, et al. In vitro evaluation of the effectiveness of ProTaper universal rotary retreatment system for gutta-percha removal with or without a solvent. J Endod 2009; 35(11): 1580–3. [CrossRef]
15. Betti LV, Bramante CM, de Moraes IG, et al. Comparison of GPX with or without solvent and hand files in removing filling materials from root canals--an ex vivo study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2010; 110(5): 675–80. [CrossRef]
16. Gokturk H, Yucel AC, Sisman A. Effectiveness of four rotary retreatment instruments during root canal retreatment. Cumhuriyet Dent J 2015; 18(1): 25–36. [CrossRef]
17. Arslan H, Abbas A, Karatas E. Influence of ultrasonic and sonic activation of epoxy-amine resin-based sealer on penetration of sealer into lateral canals. Clin Oral Investig 2016; 20: 2161–4. [CrossRef]
18. DuLac KA, Nielsen CJ, Tomazic TJ, et al. Comparison of the obturation of lateral canals by six techniques. J Endod 1999; 25(5): 376–80. [CrossRef]
19. Karabucak B, Kim A, Chen V, et al. The comparison of gutta-percha and Resilon penetration into lateral canals with different thermoplastic delivery systems. J Endod 2008; 34: 847–9. [CrossRef]
20. El Sayed M. Penetration of three endodontic sealers in simulated lateral canals during the lateral condensation technique: An in vitro study. Int J Dent 2022; 16: 2686247. [CrossRef]
21. Almeida JF, Gomes BP, Ferraz CC, et al. Filling of artificial lateral canals and microleakage and flow of five endodontic sealers. Int Endod J 2007; 40(9): 692–9. [CrossRef]
22. Hess JC, Culieras MJ, Lambiable N. A scanning electron microscopic investigation of principal and accessory foramina on the root surfaces of human teeth: Thoughts about endodontic pathology and therapeutics. J Endod 1983; 9(7): 275–81. [CrossRef]
23. Kasahara E, Yasuda E, Yamamoto A, et al. Root canal system of the maxillary central incisor. J Endod 1990; 16(4): 158–61. [CrossRef]
24. Omidi S, Rahmanirad S, Jafari A, et al. Retrieval of AH Plus, MTA Fillapex, and Endoseal MTA in endodontic retreatment: An in vitro cone-beam computed tomography study. Front Dent 2025; 22: 38. [CrossRef]
25. Neelakantan P, Grotra D, Sharma S. Retreatability of 2 mineral trioxide aggregate-based root canal sealers: A cone-beam computed tomography analysis. J Endod 2013; 39(7): 893–6. [CrossRef]
26. Carpenter MT, Sidow SJ, Lindsey KW, et al. Regaining apical patency after obturation with gutta-percha and a sealer containing mineral trioxide aggregate. J Endod 2014; 40(4): 588–90. [CrossRef]
27. Müller GG, Schönhofen ÂP, Móra PM, et al. Efficacy of an organic solvent and ultrasound for filling material removal. Braz Dent J 2013; 24(6): 585–90. [CrossRef]
28. Sağlam BC, Koçak MM, Türker SA, et al. Efficacy of different solvents in removing gutta-percha from curved root canals: A micro-computed tomography study. Aust Endod J 2014; 40(2): 76–80. [CrossRef]
29. Ferreira I, Pina-Vaz I. The novel role of solvents in non-

surgical endodontic retreatment. Appl Sci 2022; 12(11): 5492. [CrossRef]
30. Schäfer E, Zandbiglari T. A comparison of the effectiveness of chloroform and eucalyptus oil in dissolving root canal sealers. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2002; 93(5): 611–6. [CrossRef]
31. Alzraikat H, Taha NA, Hassouneh L. Dissolution of a mineral trioxide aggregate sealer in endodontic solvents compared to conventional sealers. Braz Oral Res 2016; 30: e16. [CrossRef]