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Effect of Solvent Use on Dentinal Integrity and Filling Removal During Endodontic Retreatment: A Micro-Computed Tomography Study

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Abstract

Introduction: This study evaluated, using micro-computed tomography (micro-CT), whether solvent use during endodontic retreatment influences dentinal defect formation and the removal of filling material compared with mechanical retreatment alone. **Materials and Methods:** Twenty extracted human mandibular molars were prepared and obturated using standardized protocols and randomly allocated to solvent-assisted retreatment or retreatment without solvent (n=10 per group). Micro-CT scans were obtained before treatment, after obturation, and after retreatment at a voxel size of 13.68 µm. Dentinal defects were assessed using axial images, and residual filling-material volume was measured three-dimensionally in the apical, middle, and coronal thirds. Between-group comparisons were performed using the Welch independent-samples t-test or Mann–Whitney U test, as appropriate. Within-group comparisons were performed using the Friedman test. **Results:** No dentinal defects were detected in any specimen (0/20). However, the exact 95% confidence interval indicated that a low-incidence effect could not be excluded. Residual filling material was detected in all canals after retreatment. No significant differences were observed between the solvent-assisted and non-solvent groups in residual filling-material volume at any canal third after adjustment for multiple comparisons (all adjusted $P>0.05$). **Conclusions:** Under the conditions of this in vitro study, solvent use did not significantly improve filling-material removal compared with mechanical retreatment alone. No dentinal defects were detected in either group; however, the exploratory nature and limited sample size of the dentinal-defect analysis preclude excluding a low-incidence effect.

Keywords: Endodontic Retreatment; Micro-computed Tomography; Dentinal Defects; Solvent; Residual Filling Material; Gutta-Percha

Introduction

Vertical root fractures are a significant complication affecting long-term endodontic outcomes and tooth retention [1]. These fractures typically originate from stress concentrations within the root canal dentin, with pre-existing defects serving as initiation sites for crack propagation [2]. Iatrogenic dentinal damage during endodontic procedures, particularly during the instrumentation and retreatment phases, has emerged as a critical concern in clinical practice [3]. Consequently, preservation of dentinal integrity during primary treatment and retreatment procedures is of critical clinical importance.

A multitude of methodologies have been proposed for retreatment protocols aimed at the removal of gutta-percha and sealing materials, employing adjunctive chemical solvents or not, through the utilization of stainless-steel hand files or nickel-titanium rotary instruments, Gates-Glidden burs, thermally activated devices, ultrasonic apparatuses, and laser technology [4]. Micro-computed tomography (micro-CT) is considered the gold standard for the non-destructive investigation of dentin structure during endodontic procedures [5, 6]. Unlike conventional sectioning techniques, micro-CT enables the serial evaluation of individual specimens across treatment stages, providing superior sensitivity for detecting subtle microstructural changes [7]. Recent micro-CT investigations have documented instrumentation-related defects in primary treatment [8, 9]. In contrast, studies investigating the use of chemical solvents during retreatment have primarily focused on their effectiveness in facilitating filling material removal, with inconsistent findings regarding their clinical benefits [10, 11]. To our knowledge, no previous micro-computed tomography study has simultaneously evaluated the influence of solvent use on both dentinal defect formation and filling material removal during endodontic retreatment. Dentinal integrity was the primary biological outcome, while residual filling material was evaluated as a complementary measure of retreatment efficacy. Therefore, this study used high-resolution micro-CT to investigate whether solvent use during retreatment influenced dentinal-defect formation or filling-material removal compared with mechanical retreatment alone. The null hypotheses were that solvent use would not affect either outcome.

Materials and Methods

This study was approved by the Clinical Research Ethics Committee of the Faculty of Dentistry, Istanbul University (approval number: 2018/69-Rev/2; date: 26 September 2019). All procedures were performed in accordance with the Declaration of Helsinki (2013).

Sample Selection

Our study included 20 extracted human mandibular molars with mesial root canal curvatures between 10° and 20°, obtained from the Department of Oral and Maxillofacial Surgery, Istanbul University Faculty of Dentistry. The reasons for extraction were unknown.

An a priori sample-size calculation was performed using PASS 15 (NCSS LLC, Kaysville, UT, USA) for a continuous filling-material removal outcome. Assumed group means of 1.1 and 1.6 with a common standard deviation of 0.4 indicated that 10 specimens per group would provide approximately 80% power for a two-sided, equal-variance t-test at $\alpha=0.05$. This calculation did not apply to the binary dentinal-defect outcome, which was treated as exploratory.

Canal curvature was determined from buccolingual radiographs using Schneider's technique and ImageJ software (National Institutes of Health, Bethesda, MD, USA). After the residual soft tissues were removed using a scalpel and periodontal curette, the teeth were stored in distilled water containing thymol crystals at 4°C.

The specimens were initially examined visually and radiographically. Following radiographic screening, all specimens underwent baseline micro-computed tomography (micro-CT) analysis (CTAn v.1.13, Bruker-microCT) to detect preexisting dentinal defects. Only specimens confirmed to be free of dentinal defects were included to ensure an accurate longitudinal assessment.

Specimens were randomly allocated to two independent groups (n=10 per group) using a computer-generated randomization program (www.randomizer.org): solvent-assisted retreatment and non-solvent retreatment. One canal per tooth was selected for instrumentation, obturation, and retreatment procedures; one treated canal per tooth constituted the unit of analysis.

To simulate the periodontal ligament, the root surfaces were dipped in melted pink wax and vertically embedded in cylindrical cold-cure acrylic resin blocks. After polymerization, the roots were removed, and the wax was eliminated using hot water and gauze. The resulting root-shaped voids were filled with a flowable polyether impression material (Impregum Garant Soft, 3M ESPE, Seefeld, Germany), and the roots were reinserted to create a thin layer around the root surface, as previously described [1, 2, 8].

Preparation and Obturation of Root Canals

The working length was established by inserting a size #10 K-file until it was visible at the apical foramen and subtracting 1 mm. Initial scouting was performed using #10 and #15 K-files. Canal preparation was completed using the Revo-S NiTi rotary system (SC1, SC2, SC3) driven by an X-Smart motor (Dentsply Maillefer, Ballaigues, Switzerland) according to the manufacturer's instructions.

Irrigation was performed with 2 mL of 2.5% NaOCl between instruments using a 30-gauge needle (NaviTip, Ultradent, South Jordan, UT, USA). After rotary preparation, the canals were enlarged to a master apical size of #35 using stainless-steel files with the balanced-force technique. Final irrigation comprised 5 mL of 2.5% NaOCl, 5 mL of 17% EDTA, and 5 mL of distilled water. No sonic, ultrasonic, or laser activation was used to isolate the effect of the solvent [12].

The canals were dried with paper points and obturated using cold lateral condensation with #35 master gutta-percha and AH Plus sealer (Dentsply DeTrey, Konstanz, Germany). Access cavities were sealed with Cavit-G (3M ESPE, Seefeld, Germany). Following obturation, the specimens were stored at 37°C in 100% humidity for 2 weeks to allow complete setting of the sealer. The second micro-CT scan was performed after this two-week storage period and before the retreatment procedures.

Following obturation, conventional periapical radiographs were obtained to verify the quality of the root canal filling and the absence of voids.

Root Canal Retreatment Procedures

ProTaper Universal Retreatment instruments (Dentsply Maillefer, Ballaigues, Switzerland) were selected because they are widely used and have been extensively evaluated for solvent-

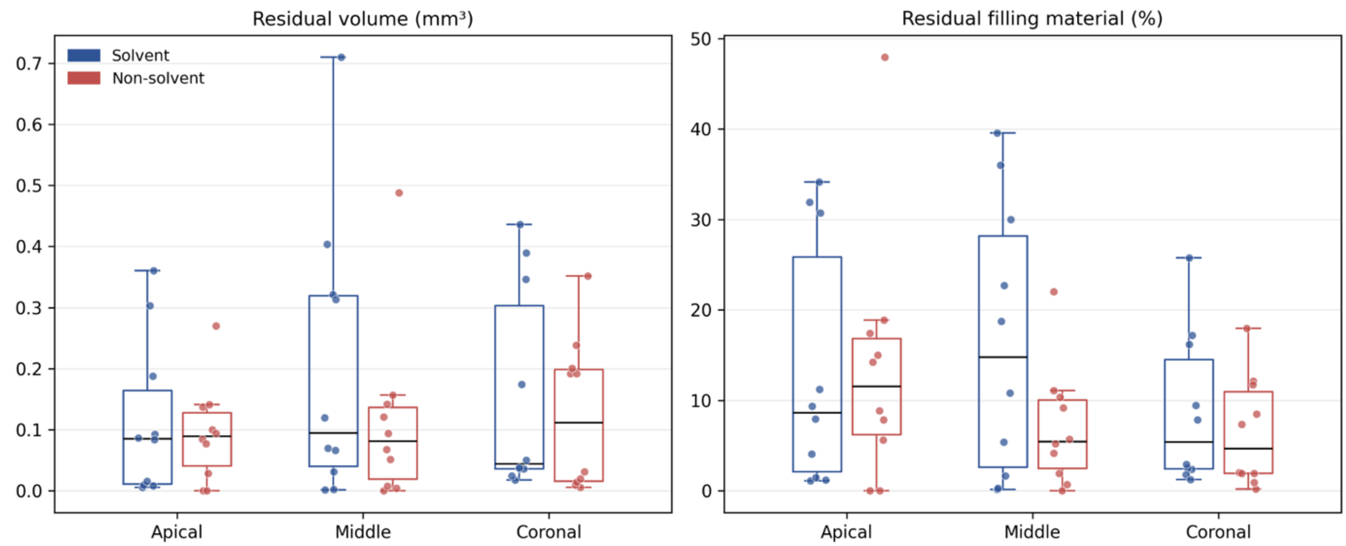

Figure 1. Representative three-dimensional micro-CT reconstruction and corresponding axial sections at five root levels. Images show the canal after initial filling, after retreatment, and after spatial registration and superimposition of the two datasets. In the superimposed images, blue represents registered root dentin and magenta represents residual filling material

assisted gutta-percha removal [13-17]. Retreatment was performed at 500 rpm and 200 g·cm torque. In both groups, D1 was initially used to remove the coronal filling material and create a reservoir. In the solvent group, 0.1 mL of the eucalyptol-based solvent Guttasolv (Septodont, Saint-Maur-des-Fossés, France) was applied once and allowed to act for 1 min; no additional solvent was used. D2 and D3 were then used sequentially to the working length. In both groups, Gates–Glidden drills sizes 2 and 3 were used coronally, followed by circumferential filing with #35, #40, and #45 K-files. The non-solvent group followed the same instrumentation and irrigation protocol without solvent. Retreatment was completed when no visible gutta-percha remnants were observed in the irrigating solution after the final instrument.

After retreatment, a single control radiograph of each specimen was obtained in the buccolingual direction to assess the presence of radiographically detectable filling material before micro-CT scanning. Subsequently, the specimens were rescanned using micro-CT as the third evaluation time point. Radiographs were used solely for verification and were not included in the quantitative analysis.

Micro-CT Analysis

Each specimen underwent three micro-CT scans at the micro-CT laboratory of the Inönü University Scientific and Technological Research Center (İBTAM): (1) before root canal preparation, to obtain baseline images; (2) after root canal preparation, obturation, and the two-week storage period allowed for sealer setting; and (3) immediately after completion of the retreatment procedure. All scans were performed using a SkyScan 1172 system (Bruker-microCT, Kontich, Belgium) with identical acquisition parameters.

The X-ray tube was operated at 100 kV and 100 µA with an isotropic voxel size of 13.68 µm. Aluminum (0.5 mm) and copper (0.038 mm) filters were used. Images were acquired over a 180° rotation around the vertical axis using a rotation step of 0.5°, an exposure time of 2000 ms, and two-frame averaging. Each scan required approximately 1 hour and generated approximately 1000 axial images per specimen.

Projection images were reconstructed using NRecon software (version 1.6.4; Bruker-microCT) with 45% beam-hardening correction, a smoothing value of 3, an attenuation coefficient range of 0–0.1, and appropriate ring-artifact correction. The reconstructed baseline, post-obturation, and post-retreatment datasets were three-dimensionally co-registered using DataViewer software (version 1.5.1; Bruker-microCT) to ensure correspondence between anatomical planes. For volumetric comparison, the post-retreatment target dataset was spatially registered to the corresponding post-obturation reference dataset. Representative micro-CT images are presented in Fig. 1.

Dentin Defect Evaluation

Axial micro-CT images were examined for the presence of dentinal defects using CTAn software (version 1.13; Bruker-microCT). For each specimen, images obtained before preparation, after obturation, and after retreatment were examined separately from the apical foramen to the root canal orifices. Before the formal assessment, the examiners underwent a calibration session using representative axial micro-CT slices to establish common criteria for identifying and classifying dentinal defects and distinguishing them from imaging artifacts. Following calibration, dentinal-defect assessment was performed independently by two experienced endodontists who were blinded to group allocation. The independent assessments were recorded before any consensus evaluation. In cases of uncertainty or disagreement, the corresponding dataset was jointly re-evaluated until consensus was reached. Interobserver agreement was assessed by cross-tabulation and Cohen's kappa; percentage agreement was reported when kappa was not estimable because all observations belonged to a single category.

Residual Volume of Filling Material

Registered post-obturation and post-retreatment datasets were analyzed using CTAn software (version 1.13; Bruker-microCT). For each specimen, the working length was divided into equal coronal, middle, and apical thirds. A standardized, stage-specific segmentation protocol was applied. Because the compact post-obturation filling mass and the smaller, dispersed post-retreatment remnants showed different grayscale distributions, threshold ranges were determined separately for the two imaging stages by examining the density histograms together with the corresponding axial grayscale images. Once established, the thresholds were fixed and applied without specimen-specific modification to all datasets within the respective stage. Grey-value ranges of 193–255 and 130–255 were used for the post-obturation and post-retreatment datasets, respectively. The resulting binary segmentations were visually cross-checked against the corresponding grayscale images before volumetric calculation. No separate algorithmic correction was applied for partial-volume effects. Filling-material volumes were quantified three-dimensionally for each canal third and for the entire canal. All measurements were recorded in mm^3, and the percentage of residual filling material was calculated relative to the corresponding post-obturation filling volume. Three-dimensional models were generated using CTAn and visualized using CTVol software (version 2.2.3; Bruker-microCT). All volumetric measurements were performed twice on separate occasions by the same examiner to verify measurement consistency. In cases of uncertainty regarding segmentation or the delineation of residual filling material, the corresponding datasets were additionally reviewed by a second experienced endodontist, and the final segmentation was determined by consensus.

Statistical Analysis

Statistical analyses were performed using SPSS v.17.0 (SPSS Inc., Chicago, IL, USA), with confirmatory re-analysis in Python (SciPy). Normality was assessed with the Shapiro-Wilk test, appropriate for the present sample size (n=10 per group). Normally distributed variables are summarised as mean±standard deviation and non-normally distributed variables as median (interquartile range); both are reported for residual-material outcomes because several were right-skewed.

The unit of analysis was the treated canal (one canal per tooth). The untreated canal was used solely as an internal control for baseline assessment and was not included in between-group comparisons. Between-group comparisons used the independent-samples t-test (Welch correction) for normally distributed variables and the Mann-Whitney U test otherwise. For each residual filling material comparison, an effect size with a 95% confidence interval was reported (Hedges' g together with the mean difference for parametric comparisons, and rank-biserial correlation together with the Hodges–Lehmann median shift and bootstrap 95% confidence interval for non-parametric comparisons). To address multiplicity, p-values were adjusted within each outcome family using both the Holm family-wise error rate procedure and the Benjamini–Hochberg false discovery rate procedure. Statistical conclusions were unchanged under either adjustment method. Comparisons among the apical, middle, and coronal thirds of the same canal (related samples) used the Friedman test with Kendall's W reported as the effect size, followed, where significant, by pairwise Wilcoxon signed-rank post-hoc tests with Holm correction. The zero-event dentinal-defect outcome was treated as exploratory, with precision expressed as the exact (Clopper-Pearson) 95% CI; observer agreement was evaluated by cross-tabulation and percent agreement. Significance was set at alpha=0.05 (two-sided).

Results

Dentinal Defect Formation

Micro-CT evaluation revealed no dentinal defects in any specimen at any time point in either group (n=10 per group). Both examiners independently classified all 20 specimens as defect-free, giving complete inter-examiner agreement (100%; 20/20; Table 1). Because every observation fell into a single category, Cohen's kappa could not be calculated: the marginal totals had no variance, so the chance-expected agreement

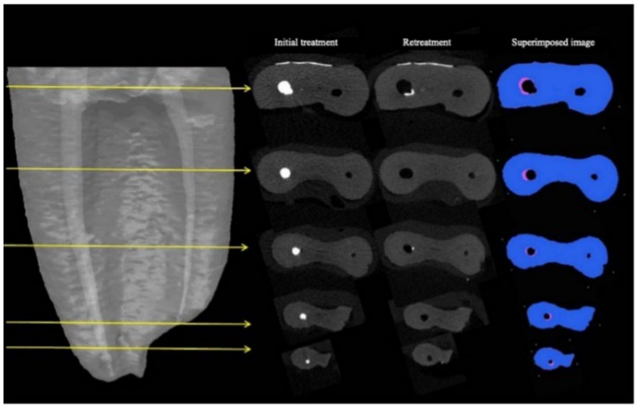

Figure 2. Representative axial micro-CT sections from the solvent-assisted (Group 1) and non-solvent (Group 2) retreatment groups at five corresponding root levels. Images were obtained before treatment, after root canal filling and the two-week sealer-setting period, and after retreatment. No new dentinal defects were detected at any evaluated stage

equalled the observed agreement and kappa was undefined the paradox described for high-agreement, low-prevalence tables [18]; the percentage of agreement is reported in its place. Because no events occurred, the exact 95% confidence interval for the true defect incidence was 0-16.8% overall and 0-30.8% within each group. Representative axial micro-CT images obtained at the evaluated treatment stages are shown in Fig. 2.

Initial Filling Volume before Retreatment

The pre-retreatment canal-filling volumes were measured separately in the apical, middle, and coronal thirds (Table 2). Intergroup comparisons revealed no statistically significant differences between the solvent-assisted and non-solvent groups at any canal level (apical: *P*=0.606; middle: *P*=0.689; coronal: *P*=0.737). However, intragroup comparisons revealed statistically significant differences among the three canal levels in both groups (*P*=0.002), with greater filling volumes observed in the coronal third.

Residual Filling Material after Retreatment

Residual filling material was detected in all specimens after retreatment. However, no statistically significant differences were observed between the solvent-assisted and non-solvent groups in the apical (*P*=0.940), middle (*P*=0.597), or coronal thirds (*P*=0.406; Table 3). The distribution of residual filling material for each canal third and group is shown as individual data points with box plots in Fig. 3; the wide, right-skewed distributions may partly reflect anatomical variability among the canals.

Intragroup comparisons of residual filling material volume among the apical, middle, and coronal thirds revealed no statistically significant differences in either group (*P*>0.05). Representative three-dimensional micro-CT reconstructions demonstrating residual filling material after retreatment are presented in Fig. 1.

Percentage of Residual Filling Material

When the residual filling material was evaluated as a percentage of the initial filling volume (Table 4), no statistically significant differences were observed between the groups in the apical (*P*=0.965), middle (*P*=0.092), or coronal thirds (*P*=0.450).

Similarly, intragroup comparisons of residual filling material percentages among the apical, middle, and coronal thirds revealed no statistically significant differences in either group (*P*>0.05).

Table 1. Interobserver agreement for dentinal-defect assessment (n=20)

	Examiner 2		
Examiner 1	**Crack: Yes**	**Crack: No**	**Total**
Crack: Yes	0	0	**0**
Crack: No	0	**20**	**20**
Total	**0**	**20**	**20**

Values are numbers of specimens. Percentage agreement was 100% (20/20). Cohen's kappa was not estimable because all observations were classified as defect-free.

Table 2. Initial filling-material volume at the apical, middle, and coronal thirds in the solvent-assisted and non-solvent retreatment groups.

Level	Solvent Used	Non-Solvent	p^1
Apical	0.77 (0.24)^{a} (0.76)	0.70 (0.28)^{a} (0.71)	0.606
Middle	1.27 (0.53)^{ab} (1.28)	1.36 (0.53)^{ab} (1.36)	0.689
Coronal	1.70 (0.64)^{b} (1.90)	1.81 (0.72)^{b} (1.97)	0.737
p^2	0.002	0.002	

Values are presented as mean (SD) (median). [1]Mann–Whitney U test; [2]Friedman test. Different superscript letters indicate significant differences among canal thirds within groups.

Table 3. Residual filling-material volume after retreatment at the apical, middle, and coronal thirds in the solvent-assisted and non-solvent groups

Residual Filling Material	Solvent Used	Non-Solvent	p^1
Apical	0.12 (0.13)^{a} (0.09)	0.09 (0.08)^{a} (0.09)	0.940
Middle	0.20 (0.23)^{a} (0.09)	0.11 (0.14)^{a} (0.08)	0.597
Coronal	0.15 (0.17)^{a} (0.04)	0.13 (0.12)^{a} (0.11)	0.406

Values are presented as mean (SD) (median). [1]Mann–Whitney U test; [2]Friedman test. Different superscript letters indicate significant differences among canal thirds within groups.

Table 4. Residual filling material expressed as a percentage of the initial filling volume in the apical, middle, and coronal thirds

Percentage	Solvent Used	Non-Solvent	p^1
Apical	13.31±13.55^{a} (8.64)	13.58±13.80^{a} (11.53)	0.965
Middle	16.52±15.07^{a} (14.77)	7.03±6.55^{a} (5.44)	0.092
Coronal	8.73±8.40^{a} (5.40)	6.46±6.03^{a} (4.67)	0.450
p^2	0.733	0.468	

Values are presented as mean (SD) (median). [1]Mann–Whitney U test; [2]Friedman test. Different superscript letters indicate significant differences among canal thirds within groups.

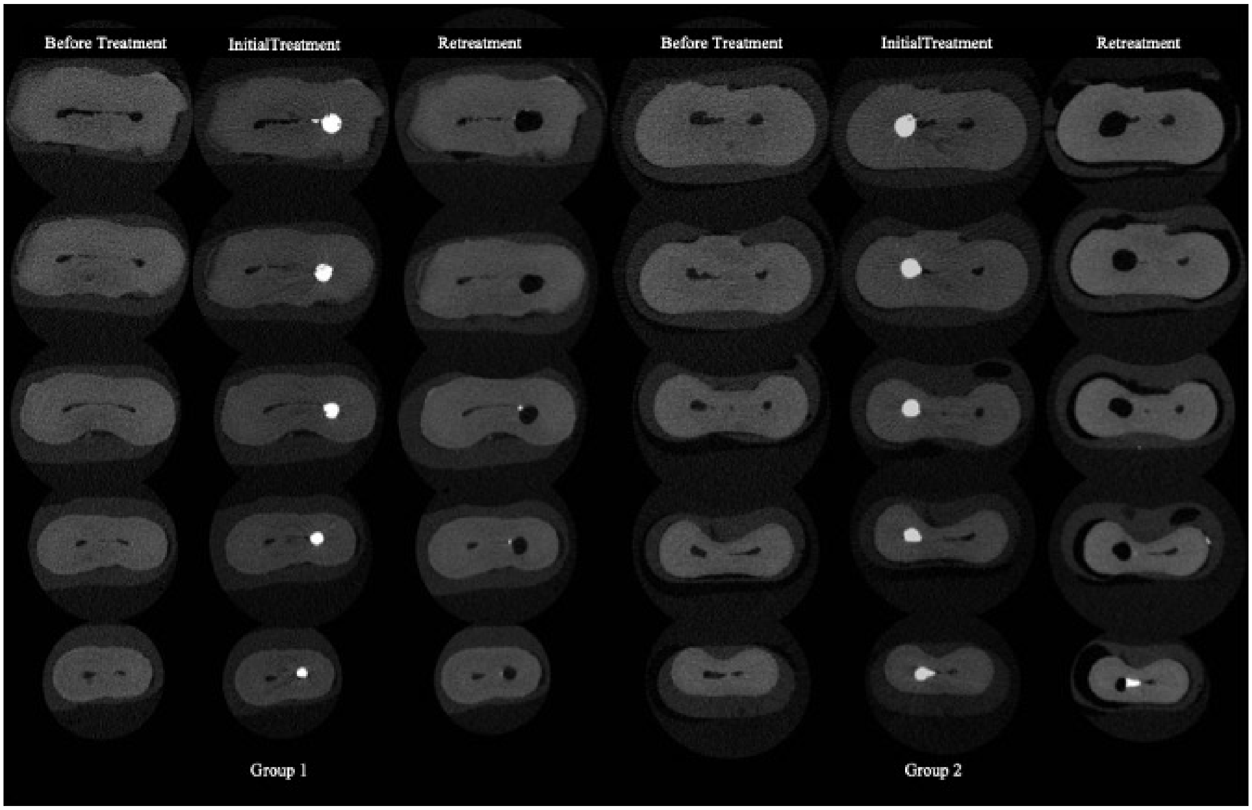

Figure 3. Residual filling-material volume (mm^3) and percentage of residual filling material relative to the initial filling volume (%) in the apical, middle, and coronal thirds of the solvent-assisted and non-solvent retreatment groups. Individual data points are overlaid on box plots; boxes represent the interquartile range and horizontal lines indicate the median. Whiskers represent the minimum and maximum values

Discussion

This micro-CT study evaluated whether solvent use influenced dentinal-defect formation or filling removal. No defects were detected in either group, and solvent use did not improve filling removal compared with mechanical retreatment alone. Therefore, the null hypothesis for filling removal was not rejected.

The use of micro-CT imaging represents a major strength of this study. Unlike destructive sectioning and optical microscopy, which may introduce defects during specimen preparation [19-21], micro-CT enables longitudinal, non-destructive evaluation of the same specimen [5, 22, 23]. To our knowledge, no previous study has assessed solvent-assisted retreatment using this longitudinal design. Although the study did not evaluate a novel solvent or instrumentation system, the within-specimen approach reduced confounding from anatomical variability and provided a methodologically distinct contribution to previous solvent-related research [24]. Longitudinal studies indicate that defects observed after treatment may represent pre-existing cracks or preparation artifacts, potentially influenced by extraction, dehydration, and age-related changes in dentin [25, 26]. Consistent with previous micro-CT studies [22, 27], no new defects were detected. A recent in vivo pilot study similarly reported no defects when instrumentation remained within the apical constriction but observed cracks after over-instrumentation [28]. The zero-event finding may have been influenced by the longitudinal assessment, maintenance of the working length 1 mm short of the apical foramen, initial enlargement to size #35, hydrated storage, and calibrated image interpretation. Nevertheless, very small defects may be affected by voxel resolution [29], and the sample size cannot exclude a low-incidence effect.

Previous studies investigating dentinal defect formation have frequently used straight-rooted incisors and premolars because of their simpler anatomy and easier standardization [4, 11]. Posterior teeth, particularly mandibular molars, present greater anatomical complexity and technical difficulty during root canal treatment and retreatment. De-Deus et al. suggested that this anatomical complexity may generate greater stress concentrations during instrumentation, potentially increasing the risk of dentinal crack formation [5].

No solvent-associated dentinal defects were observed under the conditions studied. However, because this was a zero-event outcome with limited power for detecting low-incidence effects, the findings neither demonstrate nor exclude a small effect of solvent use on dentinal-defect formation. Although solvents facilitate filling removal by softening or dissolving gutta-percha [30], concerns remain regarding their potential effects on dentin structure.

Residual material was detected in all specimens, consistent with reports that complete filling removal remains difficult [15, 31, 32]. Lim *et al.* [32] and Takahashi *et al.* [15] similarly found no significant cleaning benefit from solvent use, while Horvath et al. suggested that softened gutta-percha may penetrate dentinal irregularities and hinder removal [33]. No between-group comparison was significant. The middle-third residual percentage approached significance before adjustment (P=0.092), but this finding did not survive correction for multiple testing; the numerically greater residual material in the solvent group argued against a cleaning benefit. No validated volumetric threshold defines a clinically acceptable residual amount, and because clinical outcomes were not evaluated, the clinical relevance of the observed volumes remains uncertain.

Our findings agree with a comparable micro-CT study in curved canals, in which neither chloroform nor Endosolv R reduced residual gutta-percha compared with a no-solvent control [34], and with evidence that mechanical instrumentation performs most of the removal [14]. Reported solvent benefits appear limited to aged bioceramic fillings and novel formulations [35], which differ from the gutta-percha/AH Plus system evaluated here. Solvent use may also reduce sealer-to-dentin bond strength during re-obturation [36], while a systematic review found no reduction in postoperative pain [37]. Because Guttasolv acts primarily on gutta-percha, these findings should not be generalized to other sealer chemistries.

The absence of induced defects agrees with longitudinal micro-CT studies: Almeida *et al.* [38] found that every defect visible after retreatment was already present after obturation, and Yilmaz *et al.* [8] reported that gutta-percha removal did not increase defect incidence. The apparent conflict with reports of more cracks after retreatment [39] is likely methodological, because paired same-specimen imaging distinguishes newly formed defects from pre-existing cracks, whereas destructive or non-paired designs cannot. Thus, no defects were detected under the conditions studied, but a low incidence cannot be excluded.

Clinically, solvent use did not improve the evaluated outcomes under the conditions studied. However, this report was limited to dentinal-defect formation and residual filling material; other outcomes from the broader thesis project were outside its scope. Therefore, the findings do not support a definitive recommendation for or against routine solvent use.

The findings apply specifically to canals filled with gutta-percha and AH Plus. Retreatment efficacy varies with sealer chemistry, and comparisons between epoxy resin-based and bioceramic sealers have produced conflicting results [40]. AH Plus exhibits strong adhesion and may be difficult to remove, while the retrievability of bioceramic sealers also remains inconclusive [16]. Therefore, the present findings should not be extrapolated to other sealer types without dedicated comparative testing.

This study has several limitations. Although the periodontal ligament was simulated, the in vitro design could not reproduce cyclic masticatory loading or thermal fluctuations. The sample was restricted to mandibular first molars, and the unknown donor ages and possible extraction-induced damage may have affected crack susceptibility [25, 26]. Dentinal-defect formation was a prespecified outcome; however, the sample-size calculation was based on a continuous filling-removal outcome rather than the binary dentinal-defect outcome. Therefore, the study was not powered to exclude a clinically meaningful low-incidence effect, and the zero-event result should be interpreted within its confidence interval. The findings were also limited to one solvent, sealer, obturation technique, and retreatment system. Canal transportation, apical extrusion, instrument fatigue, thermocycling, mechanical fatigue, and postoperative outcomes were not evaluated. Future studies should use outcome-specific power analyses, dynamic loading and aging protocols, contemporary retreatment systems, and more diverse tooth types.

Conclusion

No dentinal defects were detected after retreatment in either group under the conditions studied. However, because the dentinal-defect analysis was exploratory and no events occurred, this finding should not be interpreted as evidence that solvent use has no effect on dentinal defect risk. Solvent use did not significantly improve filling material removal compared with retreatment without solvent, and residual material remained in all specimens. These conclusions are limited to the outcomes and experimental conditions evaluated in this study.

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Ethics Approval

This study was approved by the Istanbul University Faculty of Dentistry Clinical Research Ethics Committee. (Approval Number: 2018/69-Rev/2, Date: 26/09/2019). All procedures were performed in accordance with the Declaration of Helsinki (2013).

Conflict of Interest

None.

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None.

Author Contributions

Conceptualization: PZ/FH; Methodology: FH/AK/PZ; Formal Analysis and Investigation: FH/AK/PZ; Writing-Original draft preparation: F.H/PZ; Writing-review and editing: GKB/AK/FH/PZ; Supervision: AK/FH. All authors read and approved the final manuscript.

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