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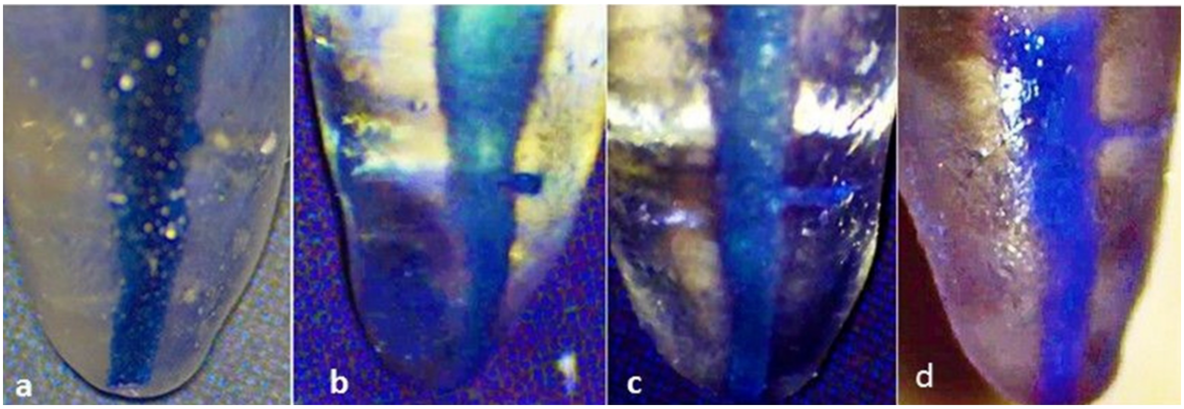

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Contact:

Address: Mevlanakapı Mah. Turgüt Özal Cad. Kemikliburun Sok. Nesrin Apt. No: 1A, Şehremini, İstanbul
Tel: +90 212 621 34 49 Fax: +90 212 621 34 50
Correspondence: +90 216 550 61 11 (Kare Publishing)

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Contents

ORIGINAL ARTICLE

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The effect of operator experience on complications in endodontic treatments: A retrospective evaluation

Idil Ozden, Hilal Hacietemoglu, Ayse Irem Koroglu, Parla Meva Durmazpinar, Hesna Sazak Ovecoglu

Department of Endodontics, Marmara University Faculty of Dentistry, Istanbul, Türkiye

Purpose: The objective of this study is to investigate the distribution of complications arising during root canal treatments performed by undergraduate and postgraduate students, and to evaluate the impact of experience level on the occurrence of these complications.

Methods: The present retrospective study evaluated endodontic treatments performed by third-, fourth- and fifth-year dental students, as well as postgraduate students at the beginning of their specialty training and those in their first, second, and third years of training. A total of 1180 root canal treatments performed due to apical periodontitis were subjected to analysis. The complications were classified into the following categories: underfilling, overfilling, inadequate shaping, ledge formation, presence of fractured instruments, apical transportation, and perforation. The collected data were then subjected to analysis using IBM SPSS version 29, and differences between the groups were assessed through the implementation of the Chi-square test ($p<0.05$).

Results: A total of 1180 cases were examined, and the most prevalent complications were identified as underfilling (16.9%), overfilling (10.8%), and inadequate shaping (10.4%). A statistically significant discrepancy was identified in the distribution of complications among undergraduate and postgraduate students ($p<0.001$). Underfilling (22.8% vs. 10.9%), inadequate shaping (14.8% vs. 5.9%), and ledge formation (5.5% vs. 0.7%) were more frequently observed in undergraduate students, whereas the incidence of overfilling was higher among postgraduate students (12.9% vs. 8.7%, $p=0.018$).

Conclusion: The present study demonstrates that the level of experience significantly affects the incidence of complications in root canal treatment. Specifically, complications such as underfilling, inadequate shaping, and ledge formation were more frequently encountered in undergraduate students, whereas postgraduate students exhibited higher rates of overfilling. The present findings underscore the imperative for more comprehensive instruction in endodontic techniques.

Keywords: Endodontic complication; operator experience; postgraduate education; root canal treatment.

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Correspondence: Idil Ozden. Department of Endodontics, Marmara University Faculty of Dentistry, Istanbul, Türkiye
Tel: +90 534 – 340 00 23 e-mail: idil.akman94@gmail.com

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Introduction

Nonsurgical root canal treatment (RCT) is a critical component of comprehensive dental care services (1,2). The primary objective of this procedure is the prevention or management of apical periodontitis through the effective cleaning, disinfection, and hermetic obturation of the root canal system (3,4). A multitude of studies have previously documented success rates that have exceeded 90% for nonsurgical RCTs that have been performed under optimal conditions (5,6). However, it has been documented that these rates decrease to approximately 40–65% when procedures are performed by less experienced practitioners (7,8). This finding emphasizes the substantial impact of clinical experience and expertise level on treatment outcomes.

RCT outcomes can be evaluated through clinical, radiographic, and histological methods (9). Notably, the technical quality of root canal obturations—predominantly evaluated through radiographic analysis—has been consistently identified in the literature as a pivotal determinant of endodontic treatment success and prognosis (10–13). A variety of procedural errors have the potential to compromise the technical success of root canal fillings (RCFs). These include termination of the filling more than 2 mm short of the radiographic apex (underfilling), extrusion of gutta-percha or sealer into the periapical tissues (overfilling), and the absence of continuous tapering from the coronal portion to the apical terminus of the canal (inadequate shaping) (14–16). An erroneous determination of the working length (WL) has the potential to exert a substantial influence on the efficacy of treatment outcomes. It has been documented that in teeth diagnosed with apical periodontitis, a 1-millimeter discrepancy in WL has been shown to result in an increased failure rate of 14% (17). Moreover, in instances of overfilling, the efficacy of treatment has been documented to decline to 75% (17,18). In addition to procedural errors, complications such as apical transportation, ledge formation, perforation, and the presence of fractured instruments within the canal are also recognized as causes of failure in RCT (5,19).

According to the curriculum guidelines established by the European Society of Endodontology (ESE), undergraduate students are obligated to attain the necessary competencies to achieve optimal outcomes in RCT during their educational training (20). Consequently, it is expected that dental undergraduate students will acquire sufficient experience in interpreting diagnostic information and performing the treatment of permanent teeth without complications. However, a review of the extant literature reveals that the success rates of root canal treatments performed by undergraduate students range from 33% to 70% (21,22). A substantial body of research has examined the correlation between treatment quality and the frequency of procedural errors, with a particular focus on molar teeth. These studies have indicated that molar teeth pose a greater challenge for both undergraduate students and general practitioners (23). In cases involving anatomical complexity or complicated conditions, intervention by endodontic specialists is necessary.

According to the core document and consensus report of the ESE regarding postgraduate education, an endodontic specialist must possess advanced knowledge, technical skills, and evidence-based clinical experience in the diagnosis and treatment of diseases of the pulp and periapical tissues (24). This report recommends that postgraduate specialty training should last a minimum of three years, during which residents are advised to perform comprehensive endodontic treatment on approximately sixty patients per year. It is emphasized that the gradual increase in case complexity throughout the training period enables residents to attain the competence necessary to successfully manage increasingly complicated endodontic cases. Despite the extensive evaluation of the quality of RCTs performed by undergraduate students, endodontists, and general practitioners in the literature, there is a paucity of sufficient data assessing the technical quality of treatments performed by students currently undergoing postgraduate specialty training. The evaluation of the technical quality of RCFs is considered a twofold process. Firstly, it serves as a means of assessing the success of RCT. Secondly, it is an important method for evaluating the effectiveness of endodontic education and practice. This highlights a gap in existing literature (25). Therefore, the objective of this study is to examine the types of complications and procedural errors that occur in RCTs performed by undergraduate and postgraduate students. Furthermore, the study seeks to ascertain the correlation between these complications and procedural errors with the type of tooth treated. This study is based on three hypotheses. First, underfilling is expected to be the most common procedural error. Second, procedures carried out by postgraduate students are anticipated to result in fewer complications and errors. Third, complications are expected to occur more frequently in molar teeth than in other tooth types.

Materials and Methods

This retrospective study was conducted in accordance with the ethical standards of the 2024 Declaration of Helsinki and was approved by the Non-Interventional Research Ethics Committee of the Faculty of Health Sciences of Marmara University (Date: 27/03/2025, No: 2025/057). The radiographic data evaluated in this study were obtained from the archives of the Department of Endodontics at Marmara University. The cases included in the study were those with the diagnostic code of “gangrene or periapical lesion” and for which RCT was completed between September 1, 2024, and January 20, 2025, at the Faculty of Dentistry, Marmara University. Conversely, cases for which obturation approval had not been obtained, cases with incomplete radiographic data, and cases treated outside the specified dates were excluded from the study. The calculation of a minimum sample size was not performed; instead, to avoid selection bias, we included all periapical radiographs that had been fully archived within the specified date range. A post-hoc power analysis was then conducted in Python (v3.12) with the statsmodels package (v0.15) using a two-proportion z-test (NormalIndPower). This analysis, based on the largest clinically relevant difference observed (incomplete filling: 22.8% vs 10.9%; Cohen h=0.32), demonstrated that our total sample (n=1,180; n_1=600, n_2=580) provides >99% power at α=0.05. Accordingly, the study is more than sufficiently powered to detect complication-rate differences of this magnitude between undergraduate and postgraduate operators.

A total of 1180 periapical radiographs that met the inclusion criteria were examined by two experienced endodontists, each with five years of clinical experience. The categorization of complications and procedural errors was conducted with a focus on the specific tooth involved and the operator’s level of expertise. In instances where consensus could not be achieved, a third specialist was consulted to facilitate agreement. During the radiographic evaluation, an analysis was conducted of the technical quality of the RCFs and the frequency of procedural errors.

Statistical Analysis

The data obtained in the study were analyzed using IBM SPSS version 29, a software program that facilitates data analysis through its suite of statistical functions. The descriptive data were presented as frequencies and percentages. The distribution of teeth presenting complications, as well as the types of complications according to the experience levels of undergraduate and postgraduate students, was examined using Chi-square tests. In all analyses, the Type I error rate was set at 5%.

Results

In this study, a total of 1180 RCTs were evaluated, performed by third-, fourth- and fifth-year undergraduate students, as well as by postgraduate students at various stages of their training. The stages of training included early stage (0–6 months), first year (6–12 months), second year (12–24 months), third year (24–36 months), and fourth year (>36 months). The study corresponded to 29, 240, 331, 36, 130, 125, 170, and 119 cases, respectively. The distribution of teeth examined is as follows: 23.6% were mandibular molars, 21.0% were maxillary anterior teeth, 16.9% were maxillary premolars, 15.1% were maxillary molars, 14.5% were mandibular premolars, and 8.9% were mandibular anterior teeth (Table 1).

The most prevalent procedural errors observed across all teeth were underfilling (16.9%), overfilling (10.8%), and inadequate shaping (10.4%), respectively. Upon analysis of the distribution of teeth evaluated according to level of experience, a statistically significant difference was identified between undergraduate and postgraduate students (Chi-square test, p<0.001). The prevalence of errors observed in maxillary anterior and maxillary molar teeth was found to be higher among postgraduate students compared to undergraduate students (24.0% vs. 18.0% for maxillary anterior teeth; 19.1% vs. 11.2% for maxillary molars). Conversely, errors were less frequent in mandibular anterior (5.5% vs. 12.2%) and mandibular premolar teeth (11.4% vs. 17.5%). When the distribution of complications was evaluated according to experience level, it was observed

Table 1. Distribution of descriptive data

Experience (n=1180)	Number (%)
3rd Grade	29 (2.5)
4th Grade	240 (20.3)
5th Grade	331 (28.1)
Resident (0)	36 (3.1)
Resident (1)	130 (11.0)
Resident (2)	125 (10.6)
Resident (3)	170 (14.4)
Resident (4)	119 (10.1)
Complications	**Number (%*)**
Incomplete Filling	200 (16.9)
Overfilling	127 (10.8)
Inadequate Shaping	123 (10.4)
Ledge	37 (3.1)
Broken File	27 (2.3)
Transportation	23 (1.9)
Perforation	6 (0.5)
Tooth Type	**Number (%)**
Mandibular Molar	278 (23.6)
Maxillary Premolar	200 (16.9)
Maxillary Anterior	248 (21.0)
Maxillary Molar	178 (15.1)
Mandibular Premolar	171 (14.5)
Mandibular Anterior	105 (8.9)

* Only the distribution of affirmative responses is presented.

Table 2. Distribution of complications experienced, and teeth involved according to operators' experience

Tooth Type	Student (%*)	Resident (%*)	p value**
Maxillary Anterior	108 (18.0)	140 (24.1)	**<0.001**
Maxillary Premolar	108 (18.0)	92 (15.9)	
Maxillary Molar	67 (11.2)	111 (19.1)	
Mandibular Anterior	73 (12.2)	32 (5.5)	
Mandibular Premolar	105 (17.5)	66 (11.4)	
Mandibular Molar	139 (23.2)	139 (24.0)	
Complication* **	**Student (%*)**	**Resident (%*)**	**p value**
Incomplete Filling (n=200)	137 (22.8)	63 (10.9)	**<0.001****
Overfilling (n=127)	52 (8.7)	75 (12.9)	**0.018****
Inadequate Shaping (n=123)	89 (14.8)	34 (5.9)	**<0.001****
Ledge (n=37)	33 (5.5)	4 (0.7)	**<0.001******
Broken File (n=27)	11 (1.8)	16 (2.8)	0333****
Transportation (n=23)	15 (2.5)	8 (1.4)	0.207****
Perforation (n=6)	5 (0.8)	1 (0.2)	0.218****

*Column percentages are presented. ** Pearson's Chi-Square Test. *** For ease of interpretation, only the distribution of affirmative responses is presented. **** Fisher's Exact Test.

Table 3. Distribution of teeth associated with observed complications

Complications	Anterior (n=353) Number (%*)	Premolar (n=371) Number (%*)	Molar (n=456) Number (%*)	p value**
Incomplete Filling (n=200*)	42 (11.9)	73 (19.7)	85 (18.6)	0.006
Overfilling (n=127*)	29 (8.2)	37 (10.0)	61 (13.4)	0.053
Inadequate Shaping (n=123*)	53 (15.0)	42 (11.3)	28 (6.1)	<0.001
Ledge (n=37*)	5 (1.4)	8 (2.2)	24 (5.3)	0.003
Broken File (n=27*)	1 (0.3)	5 (1.3)	21 (4.6)	<0.001
Transportation (n=23*)	4 (1.1)	10 (2.7)	9 (2.0)	0.315
Perforation (n=6*)	1 (0.3)	1 (0.3)	4 (0.9)	0.368

* Only the distribution of the affirmative responses is presented. ** Pearson's Chi-Square Test.

that undergraduate students exhibited higher rates of underfilling, inadequate shaping, and ledge formation, whereas postgraduate students exhibited a higher frequency of overfilling (Table 2).

Regardless of operator experience, an evaluation of the complications encountered in different teeth revealed that inadequate shaping was significantly more prevalent in anterior teeth compared to molar and premolar teeth ($p<0.001$). The prevalence of underfilling, ledge formation, and fractured instrument complications was found to be significantly higher in molar teeth ($p=0.003$ and $p<0.001$, respectively). No statistically significant differences were identified among the groups with respec4t to overfilling, apical transportation, and perforation ($p>0.05$) (Table 3).

Discussion

The current study was conducted with the objective of analyzing the types of complications and procedural errors that occurred in RCTs performed by undergraduate and postgraduate students. The study found that the most frequently treated teeth were mandibular molars (23.6%) and maxillary anterior teeth (21.0%). This finding is consistent with the reports of several studies (26–28). Mandibular molars demonstrate a higher propensity for early caries development and the necessity for RCT due to their accelerated eruption and morphology, which fosters plaque retention. Conversely, maxillary anterior teeth exhibit heightened vulnerability to pulp diseases resulting from trauma and are consequently among the teeth most frequently subjected to RCT. A comprehensive analysis of RCTs revealed that underfilling emerged as the most prevalent complication, followed by overfilling and inadequate shaping. This finding aligns with the literature to date on the subject (29,30). The first hypothesis of the study was thus confirmed.

When the types of complications were analyzed according to the level of experience, it was observed that undergraduate students encountered complications such as underfilling, inadequate shaping, and ledge formation more frequently compared to postgraduate students (p<0.001; p<0.001; p<0.001, respectively). These complications have been attributed to multiple factors, including inadequate determination of WL, suboptimal obturation techniques, the use of non-flexible files, the presence of highly curved and narrow canals (particularly in molars), and insufficient irrigation after each instrumentation step (31,32). In addition to the inadequate clinical experience of undergraduate students, their reliance on manual instrumentation may further explain the higher incidence of ledge formation, inadequate shaping, and underfilling observed in this group. However, it is acknowledged that certain academic institutions employ rotary file systems in their undergraduate clinical practices. Studies conducted in France and Spain have reported that undergraduate students perform root canal treatments using rotary file systems in all educational institutions (33,34). The early integration of rotary systems into the curriculum is emphasized to enable students to perform safer and more successful treatments in a shorter period of time (35). In the study by Matoug-Elwerfelli et al. (36), it was demonstrated that the utilization of rotary file systems led to a reduction in procedural errors by approximately 40% in comparison with conventional hand instruments. A notable decline was observed, particularly with regard to ledge formation, perforations, and filling errors. In a similar study, De Oliveira et al. (37) reported that novice students could achieve satisfactory outcomes when using rotary systems. Conversely, the integration of rotary NiTi files within the scope of endodontic education necessitates a distinct learning curve. Research has demonstrated that experienced clinicians exhibit a reduced incidence of technical errors when compared to inexperienced operators when utilizing these systems (38).

From the students' perspective, evaluations indicate that rotary systems are generally well received. Students have reported that these systems offer several advantages, including time savings and a less physically demanding working environment (39). However, certain studies have also observed that a paucity of practical experience may result in students exhibiting diminished confidence when operating rotary systems in comparison to hand instruments (40). A study conducted in Brazil reported that the utilization of rotary systems contributed positively to clinical skills. However, the study emphasized that this association could not be directly associated with overall treatment success (41). This finding indicates that while the integration of technological equipment into education offers significant advantages, clinical outcomes are influenced by multifactorial elements.

The findings of this study indicated that postgraduate students demonstrated a significant higher frequency of overfilling in comparison with undergraduate students. This discrepancy may be ascribed to the observation that postgraduate students exhibited a higher frequency of treatment on maxillary anterior teeth, which are predisposed to open apices due to traumatic injuries. Another potential explanation for this phenomenon is the increased use of rotary instruments by postgraduate students. At the commencement of their specialty training, students may encounter difficulties in maintaining WL due to challenges in following the plastic stopper on rotary files. A similar body of research has indicated that the overfilling rate tends to rise among less experienced operators when using rotary systems in comparison with hand files (29,33). Considering these findings, the second hypothesis of our study was partially supported. Although underfilling, inadequate shaping, and ledge formation were more frequently encountered by undergraduate students, overfilling was observed more often among postgraduate students. No statistically significant difference was found between the two groups regarding apical transportation or perforation. When the types of complications were analyzed according to the level of experience, it was observed that undergraduate students encountered complications such as underfilling, inadequate shaping, and ledge formation more frequently compared to postgraduate students (p<0.001; p<0.001; p<0.001, respectively). These complications have been attributed to multiple factors, including inadequate determination of WL, suboptimal obturation techniques, the use of non-flexible files, the presence of highly curved and narrow canals (particularly in molars), and insufficient irrigation after each instrumentation step (31,32). In addition to the inadequate clinical experience of undergraduate students, their reliance on manual instrumentation may further explain the higher incidence of ledge formation, inadequate shaping, and underfilling observed in this group.

The present study ascertained that the nature and frequency of complications exhibited variability according to the postgraduate year of training. As postgraduate students approached the completion of their specialty education, the incidence of inadequate shaping and underfilling pro-

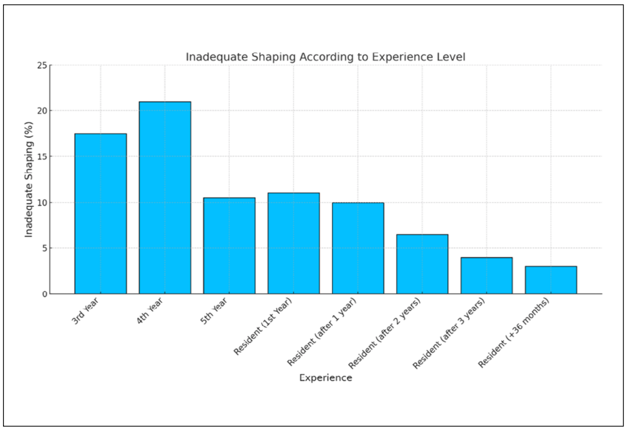

Fig. 1. Distribution of the percentage of inadequate shaping according to experience.

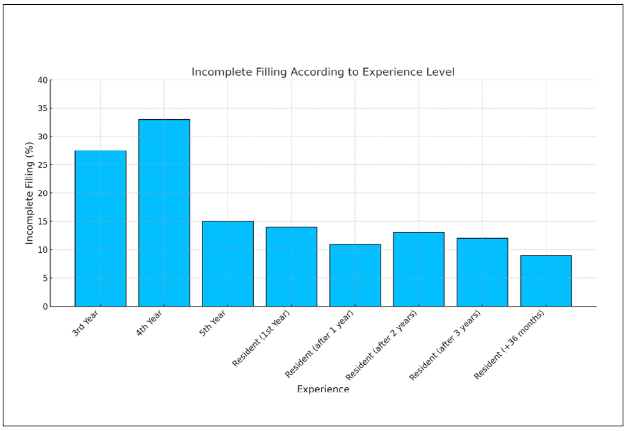

Fig. 2. Distribution of the percentage of incomplete filling according to experience.

gressively decreased (Figs. 1 & 2). A higher frequency of complications was observed among fourth-year students compared to third- and fifth-year students. This finding aligns with the extant literature (34). This phenomenon can be attributed, at least in part, to the observation that fourth-year students manage a greater number of patients than third-year students but possess less clinical experience than fifth-year students. Conversely, as no other studies have evaluated complication rates according to the level of postgraduate education, direct comparisons with existing data in literature are not possible.

When complications were evaluated according to tooth type, irrespective of operator experience, it was determined that underfilling, ledge formation, and the presence of fractured instruments were more frequently encountered in molar teeth compared to other tooth groups. A substantial body of research has been conducted on the subject, and the results of these studies support the observation that endodontic procedural errors are more commonly observed in molar teeth (23,35–38). This pattern may be due to the complex root and root canal anatomy of molar teeth, which predisposes them to such errors. Conversely, inadequate shaping was observed more frequently in anterior teeth, a finding that stands in contrast to the prevalence of other types of complications. This finding may be attributed to the anatomical characteristics of anterior teeth, which are known to exhibit wider and straighter canals. In such cases, the operator may prematurely conclude that sufficient shaping has been achieved, resulting in inadequate canal preparation. Considering these findings, the third hypothesis of the study was partially accepted. In the current study, no statistically significant association was identified between tooth type and the occurrence of perforation or apical transportation. This result is inconsistent with the findings reported in the previous research (36,38). In a retrospective study conducted by Matoug-Elwerfelli et al. (36), procedural errors were analyzed according to tooth type. The study found that both perforation and apical transportation occurred significantly more frequently in molar teeth. This discrepancy may be attributed to the reduced sample size and the exclusive use of stainless-steel hand instruments in the earlier study.

The present study aims to elucidate the impact of clinical experience on the occurrence of complications by comparing complication rates in root canal treatments performed by dental students and postgraduate students. The findings of the study indicated a decline in complication rates with an increase in experience. However, a higher prevalence of specific complications, such as overfilling, was observed among postgraduate students. These findings suggest that postgraduate education plays a critical role in the development of endodontic skills and that clinical experience is particularly effective in preventing common complications such as underfilling and inadequate shaping. A notable limitation of this study is that the assessment of root canal treatment success was based solely on two-dimensional evaluations using periapical radiographs and was conducted retrospectively. A notable limitation of the study is its restriction to a single center, which may limit the generalizability of the findings to institutions offering undergraduate and postgraduate dental education. Additionally, the evaluation of the treatments was limited to the technical quality at the conclusion of the interventions, with no subsequent follow-up assessments conducted. Consequently, a direct correlation between technical quality and clinical success cannot be established. The necessity for long-term and prospective studies in this area is evident.

Conclusion

In consideration of the study's limitations, it was ascertained that the extent of clinical experience exerts a substantial influence on the quality of endodontic treatment. The increased incidence of complications —such as underfilling, inadequate shaping, and ledge formation—observed among undergraduate students indicates that limited clinical exposure may predispose less experienced operators to procedural errors. In light of these findings, it is imperative to enhance the diversity of clinical cases and technical knowledge provided during endodontic education, and to establish structured and progressive clinical training programs for students. Furthermore, future prospective studies focusing not solely on technical success but also on long-term post-treatment clinical outcomes would make substantial contributions to the extant literature.

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Informed consent: Written informed consent was obtained from patients who participated in this study.

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ORIGINAL ARTICLE

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Effects of solvents on the adhesion of glass fiber posts to root canal dentin: An in vitro study

Evren Sariyilmaz,[1] Ersan Celik,[2] Elif Bahar Cakici,[3] Fatih Cakici,[3] Oznur Sariyilmaz,[1] Dogu Omur Dede,[2] Ayca Tulga[4]

[1]Department of Endodontics, Çanakkale Onsekiz Mart University Faculty of Dentistry, Çanakkale, Türkiye
[2]Department of Prosthodontics, Ordu University Faculty of Dentistry, Ordu, Türkiye
[3]Department of Endodontics, Ordu University Faculty of Dentistry, Ordu, Türkiye
[4]Private clinic, Doç. Dr. Ayça Tulga Muayenehanesi, Antalya, Türkiye

Purpose: This study compared the effects of solvents (chloroform, orange oil, turpentine, eucalyptol, Endosolv R) and irrigants (5.25% sodium hypochlorite [NaOCl], distilled water) on the adhesion of glass fiber posts luted with dual-cure resin cement to root canal dentin, testing the hypothesis that solvents and NaOCl would impair bond strength.

Methods: In this in vitro study, 128 extracted human mandibular premolars were prepared, filled, and retreated using NiTi files with assigned solvents/irrigants. Post spaces were prepared, and glass fiber posts were cemented with dual-cure resin. Push-out bond strength (MPa) was measured on 1-mm-thick root slices using a universal testing machine. Data were analyzed via ANOVA and Tukey tests ($p<0.05$).

Results: Turpentine significantly reduced bond strength compared to control and other solvents ($p<0.05$). NaOCl also decreased bond strength ($p<0.05$), while Endosolv R, chloroform, eucalyptol, and orange oil showed values comparable to the control. The highest bond strength was observed with eucalyptol.

Conclusion: Turpentine and NaOCl adversely affected glass fiber post adhesion, likely due to solvent penetration or oxygen radical interference. Clinicians should avoid turpentine during retreatment and consider antioxidants with NaOCl. Further research on solvent-dentin interactions is warranted to optimize post-retreatment outcomes.

Keywords: Endodontic retreatment; glass fiber post adhesion; push-out bond strength; solvent effects.

Introduction

Retreatment is generally preferred as the first treatment option when primary root canal therapy fails. The first step of retreatment involves the removal of the previous root canal filling, which typically consists mainly of gutta-percha and root canal sealer. Various gutta-percha solvents have been recommended to facilitate the removal of gutta-percha to date (1).

Chloroform has been reported in various studies as a very effective and fast gutta-percha solvent (2,3). However, re-

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Correspondence: Oznur Sarıyılmaz. Department of Endodontics, Çanakkale Onsekiz Mart University Faculty of Dentistry, Çanakkale, Türkiye

Tel: +90 505 – 241 63 90 e-mail: oznur.sariyilmaz@comu.edu.tr

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searchers continue to search for safer alternatives due to the potential carcinogenicity of chloroform (2).

Orange oil, an essential oil, has been recommended as a biocompatible alternative to chloroform for gutta-percha dissolution (4). Eucalyptol is another non-carcinogenic and less aggressive gutta-percha solvent; however, Wourms et al. (2) reported that its solvent effect was weaker compared to chloroform.

Turpentine is an organic solvent extracted from pine trees. It can partially soften gutta-percha within a few minutes at body temperature, thus facilitating the removal of gutta-percha bulk from root canals (5). Furthermore, Kaplowitz suggested that the partial softening effect of turpentine might provide an advantage during post preparation procedures (5).

Endosolv R is a synthetic root canal filling solvent composed of 66.5g of formamide and 33.5g of phenylethyl alcohol per 100g of Endosolv R. It is recommended for the removal of phenolic resin-based root canal fillings (6).

Endodontically treated teeth are more susceptible to biomechanical failures than vital teeth (7). Consequently, these teeth may lose their coronal structure due to recurrent caries or even the regular mechanical stresses of daily function. In such cases, post systems are required to support core restorations, particularly when endodontically treated teeth have suffered extensive structural loss.

Currently, glass fiber posts are preferred due to their superior esthetic properties compared to metal alloy posts, which tend to corrode over time and may cause gingival discoloration (8). Moreover, the elastic modulus of glass fiber posts is similar to that of dentin and resin cements (9), resulting in more homogeneous stress distribution compared to metal posts (10), thereby reducing the risk of root fracture (11).

Furthermore, glass fiber posts are capable of transmitting light along their length, which enhances the polymerization quality of dual-cure resin cements (12).

Resin cements are commonly used to bond glass fiber posts within root canals, and the success of this adhesion depends on multiple factors, including the complexity of the root canal system, adequate cleaning of the post space, and the proper manipulation and delivery of resin cement throughout the canal (13).

For the removal of root canal fillings, H-type files and various endomotor-assisted NiTi retreatment file systems can be used, either with or without solvents (1). Copious irrigation is also necessary to flush out remnants of root canal filling material during the removal process.

However, previous studies have shown that the bonding strength of resin-based dental materials may be affected by chemical agents used in root canal treatment, such as sodium hypochlorite (NaOCl), EDTA, and chlorhexidine (14-16). Moreover, one study reported that the root canal solvent chloroform interfered with the adhesion of root canal sealers to root dentin (17). Similarly, Shokouhinejad et al. (18) demonstrated that retreatment procedures detrimentally affected the adhesion of Resilon/Epiphany root canal filling materials.

The aim of the present study was to compare the effects of different solvents, chloroform, orange oil, turpentine, eucalyptol, and Endosolv R, and commonly used irrigants, sodium hypochlorite and distilled water, on the adhesion of glass fiber posts luted with a dual-cure resin cement, using a push-out bond strength test in retreatment-required cases.

The null hypothesis stated that the use of different solvents and sodium hypochlorite does not affect the bond strength of glass fiber posts to root canal dentin.

Materials and Methods

The study protocol was approved by the Clinical Research Ethics Committee of Ordu University (protocol number 2015/12). The protocol of this study was carried out in accordance with the guidelines outlined in the Declaration of Helsinki.

A total of 128 extracted human mandibular premolars with fully formed apices and straight root canals were used in this study. Teeth with calcified canals, extensive caries involving the roots, previous endodontic treatment, internal or external root resorption, or any signs of previous root canal treatment were excluded.

The crowns were removed using a high-speed bur under water cooling, leaving a standardized root length of 17 mm. A #10 K-file (Dentsply Maillefer) was inserted into the canal until it became visible at the apical foramen. Working length was established by subtracting 1mm from this measurement. Teeth that did not allow sufficient working length for standard post preparation were replaced at this stage.

Root canals were prepared using primary WaveOne Gold files (#25/.07) mounted on an X-Smart Plus endomotor operating in WaveOne Gold mode. During preparation, canals were irrigated with 5 mL of 5.25% sodium hypochlorite (NaOCl) using a syringe and a 30-gauge needle (NaviTip; Ultradent, South Jordan, UT, USA). Each WaveOne Gold file was used for a maximum of three canals before being discarded.

Final irrigation was performed sequentially with 1 mL of 17% EDTA, 1 mL of distilled water, 1 mL of 5.25% NaOCl, and finally 1 mL of distilled water to remove any residual irrigants. The canals were then dried with #25 absorbent paper points.

Sixteen roots were randomly selected as the control group, and their canal orifices were sealed with a temporary restorative material (Cavit G; 3M ESPE, Germany).

The remaining teeth were obturated using an epoxy resin-based sealer (AH Plus; Dentsply Maillefer), a primary WaveOne Gold gutta-percha master cone, and #25 accessory gutta-percha cones (Diadent, Almere, Holland) using the cold lateral condensation technique. The coronal 1mm of the root canal filling was removed, and the space was sealed with temporary restorative material (Cavit; 3M ESPE, Seefeld, Germany).

All specimens were wrapped in pieces of sponge and stored at 37 °C in 100% humidity for two weeks.

At the end of the storage period, the specimens were randomly divided into eight groups as described below:

Control Group: Specimens without root canal filling (n=16)

Distilled Water Group: Root canal filling removal using NiTi retreatment files with distilled water as the irrigant (n=16)

NaOCl Group: Root canal filling removal using NiTi retreatment files with 5.25% sodium hypochlorite as the irrigant (n=16)

Endosolv R Group: Root canal filling removal using NiTi retreatment files with Endosolv R as the solvent (n=16)

Eucalyptol Group: Root canal filling removal using NiTi retreatment files with eucalyptol as the solvent (n=16)

Orange Oil Group: Root canal filling removal using NiTi retreatment files with orange oil as the solvent (n=16)

Turpentine Group: Root canal filling removal using NiTi retreatment files with turpentine as the solvent (n=16)

Chloroform Group: Root canal filling removal using NiTi retreatment files with chloroform as the solvent (n=16)

Retreatment phase

The D-Race NiTi retreatment file system (FKG Dentaire, La Chaux-de-Fonds, Switzerland), consisting of D1 (15mm length, .10 taper, size 30, active tip; operated at 1000 rpm and 1.5 Ncm torque) and D2 (25mm length, .04 taper, size 25, inactive tip; operated at 600 rpm and 1.0 Ncm torque) files, was used during the retreatment phase for all specimens.

In the distilled water group, the D1 file was advanced 1–2mm into the root canal filling, followed by irrigation with distilled water. The D1 file was then reintroduced into the canal until resistance was felt. Upon encountering resistance, the file was removed, cleaned with gauze moistened with distilled water, and the canal was irrigated again with distilled water. These steps were repeated until complete removal of the coronal root filling. The remaining root filling material was subsequently removed using the D2 file, following the same procedure.

In the NaOCl group, the root canal filling was removed following the same protocol described for the distilled water group, except 5.25% NaOCl was used as the irrigant.

In the groups utilizing solvents, the D1 file was first advanced 1–2mm into the root canal filling, followed by irrigation with 5.25% NaOCl. The access cavity was then dried with paper cones and cotton pellets. A drop of the tested solvent was applied to the root canal filling for 30 seconds, after which the coronal root filling was removed using the D1 file operated at 1000 rpm and 1.5 Ncm torque. If resistance was encountered, the file was removed, cleaned with gauze moistened with distilled water, and the canal was irrigated with NaOCl. After drying, another drop of the tested solvent was placed for 30 seconds, and instrumentation was continued until the coronal root filling was completely removed. The remaining root filling was removed using the D2 file operated at 600 rpm and 1.0 Ncm torque, following the same steps.

Following the retreatment procedures, all specimens, including the control group (which had not been obturated), were instrumented using a WaveOne Gold Medium file (35/.06) (Dentsply Maillefer) mounted on an X-Smart Plus (Dentsply Maillefer) endomotor operating in WaveOne Gold mode.

Refilling of the specimens

A Medium 35/.06 WaveOne Gold gutta-percha cone (Dentsply Maillefer) was coated with AH Plus (Dentsply Maillefer) root canal sealer and placed into the root canals of all specimens. A size 0 Buchanan heat plugger, mounted on the down-pack unit of the ElementsFree obturation system, was used to remove the gutta-percha above 5mm from the apical foramen. The remaining apical 5mm of gutta-percha was then condensed using the same heat plugger.

Post placement

The post space was prepared up to 1.8mm in diameter using a Piezzo Reamer canal drill set (Cytec Blanco; Hahnenkratt GmbH, Königsbach, Germany). The post space was irrigated with distilled water after each drill change, and an EndoActivator (Dentsply, Tulsa Dental Specialties, Tulsa, OK, USA) with a large-sized tip (35/.04) was used for final irrigation to eliminate any remnants from the post space.

A self-etch adhesive system (Clearfil SE Bond 2; Kuraray Co., Inc., Osaka, Japan) was applied to the post cavities of all specimens according to the manufacturer's instructions. Glass fiber posts were then cemented into the cavities using a dual-cure resin cement (RelyX U200; 3M ESPE, Minnesota, USA).

Obtaining slice samples

The specimens with placed glass fiber posts were embedded in autopolymerizing acrylic blocks measuring 2.5 cm in height and 10mm in diameter. From the coronal region of the posts, located 14mm from the root apex, 1-mm-thick slices were obtained using a water-cooled diamond saw mounted on a low-speed precision cutting machine (Mecatome T180; Presi, Eybens, France) operating at 750 rpm. The coronal side of each slice was marked with a fine-tipped indelible marker for the push-out tests and then stored in a 1.5 mL Eppendorf tube.

The push-out tests

The slices were placed on a plastic holder with a 1.7mm diameter hole, allowing the passage of a 1.1mm cylindrical stainless steel pushing tip. The pushing tip, mounted on the head of a universal testing machine (Autograph AGS-X; Shimadzu Co., Japan) equipped with a 5000 N load cell, was positioned at the center of the glass fiber post within the slice. A compressive force was applied at a crosshead speed of 1 mm/min until the post was dislodged from the surrounding dentin. The required force was recorded and automatically converted to megapascals (MPa) by the software of the universal testing machine.

Table 1. Mean and standard deviation values of bond strength (MPa) between glass fiber posts and dentin after the use of different solvents. Different lowercase letters indicate statistically significant differences between groups ($p<0.05$).

Groups	n	Mean (STD)
Control	16	43,87±10,36[a]
Distilled water	16	33.86 ±20.79[abc]
Sodium hypochlorite	16	23.26±10.37[bc]
Endosolv	16	37.46±16.86[ab]
Eucalyptol	16	44.1±16.08[a]
Orange oil	16	33.4637±14.52[ab]
Turpentine	16	16.85±12.67[c]
Chloroform	16	36.07±16.47[ab]
p		0.000

Statistical Analysis

The normality of the data distribution was assessed using the Shapiro-Wilk test. One-way ANOVA and post hoc Tukey tests were used to evaluate the significance between groups at a 95% confidence level. All statistical analyses were performed using SPSS version 21.0 software (SPSS Inc., Chicago, IL, USA).

Results

Turpentine significantly reduced the bonding strength of the glass fiber post to dentin compared to other the solvents tested in this study. Whereas, Endosolv R, chloroform and eucalyptol were statistically similar to the control group. ($p>0.05$).

Table 1 presents the mean and standard deviation values of the bond strength between glass fiber posts and dentin following the use of different solvents.

Bond strength in the control and eucalyptol groups was found to be significantly higher than in the sodium hypochlorite and turpentine groups ($p<0.05$). The bond strength observed in the distilled water group was similar to that of all other groups. Bond strength in the turpentine group was significantly lower than in the control, eucalyptol, Endosolv R, chloroform, and orange oil groups ($p<0.05$). Among all groups, the lowest bond strength was observed with the use of turpentine. The highest bond strength was recorded in the eucalyptol group. Bond strengths in the eucalyptol, Endosolv R, chloroform, and orange oil groups were comparable to that of the control group.

Discussion

Endodontic retreatment, which has an approximate success rate of 80%, is a preferred treatment option when conventional root canal therapy fails (19). The main goals of this procedure are to regain access to the apical region by removing the existing root canal filling, disinfect the root canal system, and subsequently perform proper obturation. Achieving these objectives requires the effective removal of the often-infected root canal filling material (20). Various methods—relying on the use of ultrasonic devices, lasers, solvents, and heat-transfer systems, either alone or in combination—have been recommended to enhance removal efficacy (4, 21-24).

The persistence of apical periodontitis after initial root canal treatment remains a significant clinical challenge, often necessitating endodontic retreatment. With a reported success rate of approximately 80% (19), retreatment is the preferred option when conventional root canal therapy fails. The primary objectives of this procedure are to regain access to the apical region by removing the previous root canal filling, thoroughly disinfect the canal system, and ensure a hermetic re-obturation.

Achieving these goals largely depends on the effective removal of the existing root canal filling materials, which are frequently associated with persistent microbial contamination (20). To enhance the efficacy of filling material removal, various adjunctive techniques have been proposed, including the use of ultrasonic devices, laser systems, chemical solvents, and heat-assisted approaches (4, 21-24).

Despite these advancements, complete removal of filling materials remains a challenge, and the choice of solvent may influence not only the cleaning efficacy but also subsequent procedures, such as glass fiber post placement. In this context, the present study aimed to evaluate how different solvents used during retreatment affect the bond strength between glass fiber posts and root dentin.

Post systems are required to restore endodontically treated teeth with extensive loss of coronal structure. Among these systems, glass fiber posts are frequently preferred by clinicians due to their advantageous properties, including an elastic modulus similar to that of dentin (9), favorable esthetics (8), and a reduced risk of root fracture (11). One of the key determinants of the long-term success of post systems is the bonding strength between the post and root dentin, which can be assessed by various mechanical tests such as push-out (25), pull-out (26), and microtensile tests (14).

While the microtensile test is highly sensitive, it is associated with a high risk of premature failure. The pull-out test, although useful for evaluating the bond strength of the entire root, does not allow regional comparisons. The push-out test, on the other hand, is considered more suitable for studies like the present one, as it enables the evaluation of bond strength at different levels of the root and can better simulate clinical conditions by adjusting the direction of the applied load (13). However, this method may produce inaccurate results with thicker slices due to uneven stress distribution. To overcome this limitation, the use of 1 mm-thick slices has been recommended (25). Therefore, in this study, 1 mm-thick slices from the coronal region of the root were used to evaluate the bonding strength of glass fiber posts to root dentin.

Previous studies have shown that root canal irrigants such as NaOCl, EDTA, and chlorhexidine affect the bonding strength of resin-based materials to root dentin by altering both the organic and inorganic components of dentin or leaving remnants such as oxygen radicals (14-16). In addition, Morris et al. (27) also reported that NaOCl interferes with the infiltration of resin-based materials into demineralized dentin, thereby detrimentally affecting the bonding strength. Similarly, the root canal filling solvent chloroform has been shown to interfere with the adhesion of root canal sealers to root dentin (17). In line with these findings, Shokouhinejad et al. (18) reported that the retreatment procedure negatively impacted the adhesion of resilon/epiphany root canal fillings. A previous study by Kaufman et al. (28), which reported that root canal filling solvents such as chloroform, xylene, and Endosolv E could affect the calcium and phosphorus levels in dentin, may provide an explanation for these effects.

This study was based on a case scenario involving the resin-post requirements of a retreatment case. The commonly recommended root canal solvents, including Endosolv R, eucalyptol, orange oil, turpentine, and chloroform, were compared to determine their effect on the bonding strength of glass fiber posts. Additionally, a previous study showed that root canal sealers could detrimentally affect the bonding strength of glass fiber posts to root dentin (29). Thus, a control group was created using specimens of posts cemented into prepared, but not filled, root canals. Another important consideration is the detrimental effect of the commonly used irrigant NaOCl on resin-based dental cements due to the degradation of NaOCl into chloride and oxygen radicals. Subsequently, the released oxygen radicals inhibit the polymerization of the resin and interfere with its penetration into the demineralized dentin (27). Therefore, these findings led us to include the "distilled water" and "NaOCl" experimental groups in this study.

In this study, comparison of distilled water and the control group shows no statistical differences in bonding strength. On the other hand, the NaOCl decreased the bonding strength. The coronal third of the root has a larger surface area than the other regions of the root so, more irrigant circulated in the coronal third of the root. Thus, the coronal region of the root encountered more oxygen radicals released from NaOCl, which might be responsible for the decrease in bonding strength in the coronal region (27). Clinicians might consider the use of antioxidant agents such as Sodium thiosulfate (Na2S2O3) for improve the decreased bonding strength due to NaOCl.

Previous studies revealed that solvents used for retreatment have an effect on the mineral levels of dentin (28,30), which may have affected the bonding strength of resin-based dental materials. Additionally, solvent residues in the root canal might interfere with the chemical setting reactions of resins, negatively affecting the bonding strength of resin post systems. Furthermore, solvents may cause remnants of gutta-percha to remain, as they dissolve the material and potentially coat the dentin walls of the canal, thereby compromising the bond strength between resin post systems and dentin by forming a physical barrier.

The results of this study showed that the use of turpentine as a retreatment solvent resulted in a statistically significant decrease in the bonding strength of glass fiber posts. However, the other tested solvents did not show a statistically significant reduction in bonding strength. The removal of dentin affected by solvents during post space preparation up to 1.8mm in diameter using a Piezzo Reamer canal drill set (Cytec Blanco) may explain why a significant reduction in bonding strength was not observed for the other solvents. On the other hand, turpentine may have penetrated the dentinal tubules more deeply than the other tested solvents, and could not be completely eliminated during the post preparation process, resulting in decreased bonding strength. Further research is needed to evaluate the penetration of different solvents into dentin and the alterations they cause on the root canal dentin surface for a more precise explanation.

One of the primary limitations of this study is that it was conducted using extracted human teeth. The physiological changes that occur in dentinal tubules post-extraction, such as dehydration, collapse of the tubule structure, or altered permeability, may influence the interaction and bonding performance of resin-based materials. Consequently, the results obtained under these in vitro conditions may not fully reflect the clinical behavior of the materials under in vivo circumstances.

Within the limitations of this in vitro study, it can be concluded that the type of solvent used during endodontic retreatment may influence the bonding strength of glass fiber posts to root dentin. Among the tested solvents, turpentine caused a statistically significant decrease in bond strength, likely due to deeper dentin penetration and incomplete removal during post space preparation. In contrast, other commonly used solvents did not adversely affect bonding performance under the tested conditions. Additionally, sodium hypochlorite negatively impacted adhesion, possibly due to the release of oxygen radicals, suggesting that the use of antioxidant agents may be beneficial. These findings underscore the importance of careful solvent selection during retreatment, particularly in cases where post placement is planned.

Based on these results, the null hypothesis was partially rejected, as only turpentine and sodium hypochlorite were found to have a significant negative effect on the adhesion of glass fiber posts.

Conclusion

Further in vivo research is warranted to comprehensively evaluate the interactions between endodontic solvents and the dentin substrate, particularly in terms of their depth of penetration and long-term effects on adhesive bonding and clinical outcomes. Additionally, potential chemical interactions between residual solvents and adhesive systems may also impact bond strength, highlighting the need for further investigation into this aspect.

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ORIGINAL ARTICLE

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Evaluation of the content quality and reliability of YouTube videos on endodontic retreatment

Ayşe Karadayi, Hatice Beyza Uzun, Emine Zeynep Kurekci

Department of Endodontics, Marmara University, Istanbul, Türkiye

Purpose: This study aimed to assess the content, educational quality, and reliability of YouTube videos on endodontic retreatment to determine their usefulness for patients, students, and dental professionals.

Methods: On February 15, 2025, a YouTube search was performed using the terms "retreatment," "repeat root canal treatment," and their Turkish equivalents. Among 85 videos screened, 35 met the inclusion criteria. Two observers independently evaluated them using a 13-item content checklist, the Modified DISCERN (mDISCERN) tool, and the Global Score for Educational Value (GSEV). Descriptive statistics, normality tests, Spearman correlation, t-tests, and Kruskal-Wallis tests were used for analysis ($p<0.05$).

Results: The mean GSEV score was 5.07±3.21, suggesting moderate educational value. The average mDISCERN score was 2.44±0.95, indicating low reliability. Retreatment indications were the most commonly discussed topic (91.4%), while contraindications and intraoperative pain were rarely mentioned. Longer videos had higher GSEV scores. No link was found between video popularity and quality. Most videos were uploaded by independent dentists (57.1%).

Conclusion: YouTube videos on endodontic retreatment show inconsistent quality and limited reliability. They can offer visual support but should not replace scientific resources. Dental professionals should help direct audiences to accurate, evidence-based content.

Keywords: Dental education; educational quality; endodontic retreatment; video reliability.

Introduction

Primary orthograde root canal treatments generally demonstrate high success rates, however, post-treatment failures are still frequently encountered (1). In such cases, the main treatment options include nonsurgical retreatment, surgical retreatment, or tooth extraction (2). Among these, nonsurgical endodontic retreatment is often the preferred approach when the goal is to preserve the affected tooth (3). According to the American Association of Endodontists, nonsurgical endodontic retreatment involves the removal of existing root canal filling material, followed by cleaning, shaping, and refilling of the root canal system (4). To make an informed clinical decision, it is essential to have a clear understanding of the procedure's indications, limitations, success rates, and potential complications (5).

Retreatment is indicated when the tooth has sufficient periodontal support and can be restored functionally

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Correspondence: Ayşe Karadayı. Department of Endodontics, Marmara University Faculty of Dentistry, İstanbul, Türkiye
Tel: +90 533 – 052 73 43 e-mail: ayse.karadayi@marmara.edu.tr
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(6). It may also be considered a preventive intervention in cases where the coronal restoration is to be replaced, but the existing root canal treatment appears radiographically inadequate - even in the absence of symptoms or apical pathology (7). On the other hand, certain clinical factors such as advanced periodontal disease, vertical root fractures, an unfavorable prognosis, complex prosthetic requirements, or the patient's own preferences may contraindicate retreatment and instead necessitate alternative approaches (8).

Prior to initiating retreatment, detailed radiographic evaluation is essential to identify potential complications from previous treatment, such as apical transportation, perforations, or fractured instruments (9). These factors can increase treatment complexity, duration, number of visits, and cost, while also potentially influencing prognosis (10,11). In cases where the root canal system can be accessed and disinfected, retreatment remains a viable and conservative option (12). However, when orthograde access to the apical area is not possible due to complications such as fractured instruments, ledging, overfilling, or severe curvature, surgical alternatives like apical surgery may be more appropriate (13,14).

Recent survey studies have shown that approximately 80% of internet users seek health-related information online (15). YouTube, in addition to being the largest and most popular video-sharing platform today, is also considered the second-largest search engine after Google (16). Furthermore, YouTube ranks as the second most popular social media platform worldwide (17). YouTube, Instagram, and Facebook is among the most widely used social media platforms globally. YouTube is frequently preferred for health information due to several factors, including its ease of use, the ability to access content without a subscription, and the fact that the expertise of content creators are often more clearly defined and predictable (18).

Although numerous videos related to retreatment procedures are available on YouTube, to the best of our knowledge, no prior study has evaluated the content, accuracy, or quality of these videos. Therefore, this study aims to fill that gap in the literature by assessing whether YouTube videos on retreatment serve as a reliable source of information for dentists, dental students, and patients in need of treatment.

Materials and Methods

Assessment of videos

On February 15, 2025, the term "Retreatment" and the Turkish equivalent/translation of "repeat root canal treatment, second root canal treatment" were searched by a single researcher on YouTube from a computer with its location set to Türkiye, through a private browser without prior login to YouTube to avoid any impact from pre-existing user browsing history or search data. The reason for this is that the YouTube algorithm offers content considering user interactions (19). The search filters were set to default, sorting the videos by 'Relevance'. As of the time of writing, YouTube's layout presented search results in a continuous feed. Therefore, it was not possible to determine the exact number of videos presented in the search results. Also, during the time of the research, the 'dislike' count on YouTube was inaccessible.

It has been reported that most YouTube users typically review the first 60 videos in the search results (20). For this study, a total of 85 videos were analyzed, including 60 videos retrieved from the search term 'retreatment' and 25 videos from the Turkish equivalent "repeat root canal treatment, second root canal treatment", all sorted by relevance. Due to the limited number of videos suggested in the Turkish search for "repeat root canal treatment, second root canal treatment" only 25 videos could be selected. Of these, 25 videos were excluded during the initial screening due to irrelevance, duplication, language differences (non-English or non-Turkish), lack of sound, titles or visuals, and the videos intended for advertising purposes. Additionally, videos shorter than 1 minute, longer than 25 minutes, or those that only briefly mentioned the topic were excluded (Fig. 1). The remaining videos were independently evaluated by two observers, each with two years of clinical experience in retreatment. The observers independently reviewed and analyzed the videos, without access to each other's evaluations. To preserve objectivity, they were blinded to the like and comment counts until the completion of the analysis. In case of disagreement, a third

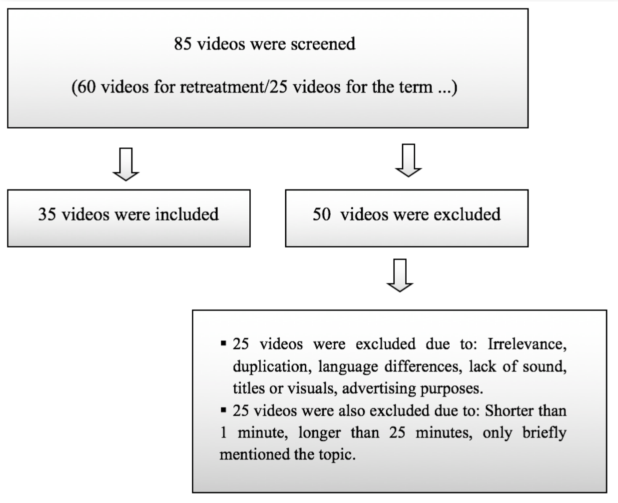

Fig. 1. Flow diagram of included and excluded videos.

Table 1. Modified DISCERN scoring system

MDISCERN Questions (1 point for each 'Yes', 0 point for 'No'.)	
1	Are the aims clear and achieved?
2	Are reliable sources of information used?
3	Is the information presented both balanced and unbiased?
4	Are additional sources of information listed?
5	Are areas of uncertainty mentioned?

researcher was consulted to achieve consensus.

Ultimately, a total of 35 videos were selected and subjected to a detailed evaluation by the observers. It took around one month to complete the video analysis and evaluation. The following parameters were recorded for each video: country of origin, source and date of upload, duration, and the number of views, comments, and likes. Using these data, interaction index (likes /total number of viewings×100) and viewing rate (Number of views/ Number of days since upload ×100%) were calculated.

The target audience of each video was determined by examining the language used and the level of scientific detail. Videos that included clinical content or used medical terms were considered to be aimed at dentists and dental students. Conversely, videos that provided a Turkish definition of "retreatment" or explicitly used the phrase "repeat root canal treatment, second root canal treatment" in Turkish were considered to be intended for a lay audience, specifically non-professionals and individuals seeking treatment.

Following a literature review on retreatment and previous YouTube/social media studies (19,20), 13 criteria were established to evaluate the selected videos: "Definition," "Indications," "Contraindications," "Alternative Treatment Options," "Success Criteria," "Clinical Application," "Treatment Duration," "Number of Sessions," "Pain During Treatment," "Complications," "Inter-session/Postoperative Symptoms," "Outcome/Restoration," and "Prognosis." If a video provided information on a given topic, it was assigned a score of "1"; otherwise, it received a score of "0." Each video's total content score was calculated by adding up the scores of individual topics (Table 1).

In line with previous studies (21-23), the quality of the videos in this study was evaluated by two independent investigators using the Modified DISCERN (mDISCERN) tool and the Global Score for Educational Value (GSEV). GSEV was determined by calculating the average of the total content score for each video. Scores between 0–2 indicated poor quality, 3-4 indicated generally low quality, 5-6 indicated moderate quality, 7-8 indicated good quality, and 9-10 indicated excellent quality.

Statistical Analysis

All statistical analyses were performed using IBM SPSS Statistics (version 21.0; IBM Corp., Armonk, NY, USA). Descriptive statistics were calculated for all variables. The Shapiro-Wilk test was used to assess the normality of the data. Based on this evaluation, Pearson's correlation coefficient was used for continuous variables with a normal distribution, while Spearman's rank-order correlation was applied for ordinal variables or when the assumption of normality was violated. The independent samples t-test was used to compare GSEV scores between two groups when parametric assumptions were met, whereas the Kruskal–Wallis test was applied for comparisons involving non-normally distributed variables. Categorical data were analyzed using the chi-square test. Interobserver agreement was evaluated using Cohen's kappa coefficient. A p-value of less than 0.05 was considered statistically significant in all analyses.

Results

A total of 85 YouTube videos were analyzed, of which 60 included the term "retreatment" and 25 featured the Turkish equivalent "second /repeat root canal treatment". To assess viewer engagement and popularity, two additional metrics were calculated: the interaction index (likes divided by total number of views, ×100) and the viewing rate (total number of views divided by the number of days since upload, ×100). Out of these, 35 videos met the predefined inclusion criteria and were subsequently evaluated in detail using 13 criteria developed for educational content assessment. Based on previous literature (20-22), the GSEV and mDISCERN scoring systems were used to evaluate the quality and reliability of YouTube videos related to endodontic retreatment. The GSEV scale, adapted from the Global Quality Scale (GQS) by Fischer et al. (21), was used to assess educational value, while the mDISCERN score, developed by Singh et al. (22), was used to evaluate the reliability of the information.

A Cohen's kappa score of 0.70 indicated a substantial level of agreement between the two reviewers.

The mean view count of the videos was 32,612.94±50,302.16, with an average duration of 4.61±5.01 minutes. The mean number of likes was 203.63±353.95, and the average number of comments was 64.17±169.93. The videos had been online for an average of 1,615.57±1,409.37 days. The average GSEV score of the analyzed videos was 5.07±3.21, reflecting a moderate level of educational content. In contrast, the mean mDISCERN score was 2.44±0.95, suggesting that the overall reliability of the information presented in the videos remained limited according to standard evaluation criteria (Table 2).

Table 2. Demographics of evaluated videos

	Mean ± SD for evaluated videos
Number of views	32612.94±50302.16
Number of likes	203.62±353.95
Number of comments	64.17±169.93
Number of days since upload	1711.296±1475.720
Interaction Index	1.42±1.47
View Rate	30229.883±7602.21
GSEV scores	5.07±2.33
MDISCERN scores	2.44±0.57

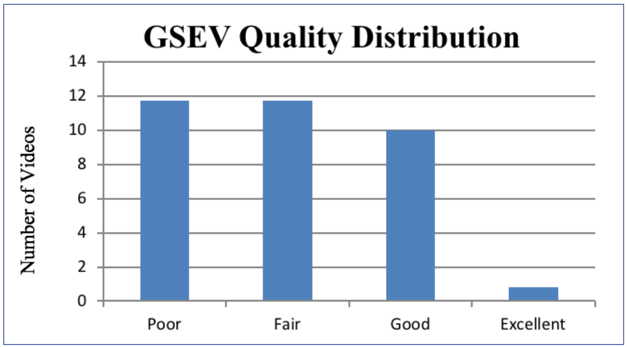

Fig. 2. GSEV quality distribution.

In the present study, 34.3% (n=12) of the videos were classified as having poor educational quality, while another 34.3% (n=12) were considered to be of fair quality. 28.6% (n=10) of the videos demonstrated good quality, and only 2.9% (n=1) reached the excellent category based on the GSEV scores (Fig. 2).

According to the MDISCERN evaluation, the majority of the videos (60.00%, n=21) were classified as low quality. A smaller proportion (34.29%, n=12) were categorized as moderate quality, while only one video (2.86%) was rated as high quality. Similarly, one video (2.86%) fell into the very low quality category. Notably, none of the videos achieved a very high-quality rating (0.00%) (Fig. 3).

According to the content analysis of the selected videos, endodontic indications were addressed in 91.4% (n=32) of the videos, making it the most frequently covered topic. This was followed by clinical procedures, discussed in 60.0% (n=21), and final restoration, included in 57.1% (n=20) of the content. Success criteria and definition appeared in 45.7% (n=16) of the videos, while alternative treatment options were mentioned in 31.4% (n=11). Less frequently addressed topics included postoperative symptoms (20.0%, n=7) and complications (45.7%, n=16). In contrast, treatment duration and intraoperative pain were only discussed in 8.6% (n=3) of the videos, and contraindications were mentioned in just 5.7% (n=2).

Notably, none of the evaluated videos addressed additional sources of information listed for patient reference or any areas of uncertainty, resulting in a failure to meet the fourth and fifth mDISCERN criteria for these videos.

The sources of the analyzed videos were distributed as follows: 8.6% were uploaded by universities, 57.1% by independent specialist dentists, 14.3% by private clinics or specialist practitioners, 5.7% by general dentists, and 11.4% by television channels (Fig. 4).

Spearman correlation analysis revealed a moderate positive correlation between GSEV and total video duration ($p<0.05$), suggesting that longer videos tend to have higher educational value. A weak correlation was observed between GSEV and mDISCERN, but it was not statistically significant ($\rho=0.21$, $p=0.229$). Similarly between video duration and mDISCERN scores ($\rho=0.23$). Also no statistically significant association found between the number of likes and either the GSEV or mDISCERN scores ($\rho=-0.06$, $p=0.738$ and $\rho=-0.06$, $p=0.733$, respectively). These results suggest that user engagement, as measured by the number of likes, does not reliably reflect the educational quality or informational reliability of You-

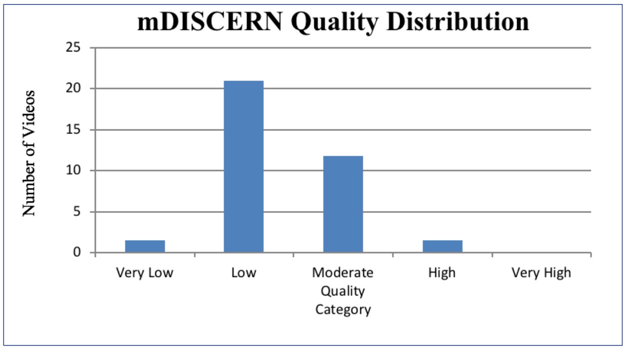

Fig. 3. Modified DISCERN quality distribution.

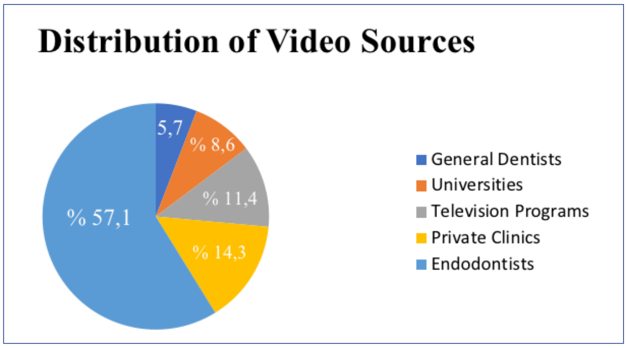

Fig. 4. Distribution of video sources.

Tube videos related to endodontic retreatment.

However, the correlation between video duration and viewing rate was negligible (ρ=–0.02), showing no meaningful association. Additionally, the mean GSEV score of the videos sourced from television programs (6.33±2.52) appeared higher than that of other sources (5.07±2.34). Although the difference was not statistically significant ($t=1.80$, $p=0.159$).

Discussion

Social media has become an increasingly popular resource for dental students to connect theoretical learning with clinical practice (20). Nawar et al. (23) found that many students see platforms like Instagram and YouTube as helpful for viewing and presenting clinical cases, even though they are aware of the limited scientific accuracy of such content. Similarly, Fu et al. (24) reported that students preferred short and comprehensible videos, especially those showing real clinical procedures, with YouTube being the most commonly used platform for learning about endodontic treatments (25).

While dental students may develop some level of critical awareness, patients and the general public often struggle to differentiate between high-quality, evidence-based content and videos that are biased or incorrect. The influence of social media on patient behavior has become increasingly evident, particularly in how patients participate in their own treatment processes. As noted by Yağcı, information obtained through these platforms can shape patients' decisions and engagement with dental care. Therefore, it is crucial that endodontic professionals engage in patient education and direct them toward high-quality, evidence-based alternatives (15).

This study aimed to evaluate the quality and educational value of YouTube videos related to endodontic retreatment using both objective content criteria and standardized scoring tools. A substantial level of interobserver agreement (κ=0.70) supports the objectivity of the content-based evaluation process.

The results showed that while topics such as indications and clinical procedures were frequently addressed, key elements like treatment duration, contraindications, and intraoperative pain were largely overlooked. Among the 35 YouTube videos analyzed, the average comment-to-view ratio was approximately 0.2%. A few videos exceeded 0.7%, indicating much higher viewer engagement. These highly interactive videos often focused on patient-centered topics and addressed common concerns such as pain after root canal treatment. In contrast, content designed for professionals or students tended to receive fewer comments, possibly due to a more passive viewing style or narrower audience.

Most of the videos were uploaded by independent endodontists (57.1%), followed by private clinics (14.3%), television programs (11.4%), universities (8.6%), and general dentists (5.7%). Additionally, when the search was conducted using the Turkish layperson's term for retreatment, the results included shorter and simpler videos, many of which were clips taken from television programs.

While viewer engagement was primarily assessed through likes, views, and comment frequency, more refined feedback tools such as polls and surveys were not available in the included videos. Moreover, most comments lacked substantive feedback on educational value or accuracy. However, two videos created by a general dentist targeted specifically at patients stood out with significantly higher comment-to-view ratios, with users often sharing personal experiences or concerns. Though informal, such interactions can offer useful insights into patient expectations and should be considered in future studies.

There are several ways to evaluate information and content shared online. These approaches allow for the assessment of online content based on different criteria (17). In many studies evaluating the quality of information on YouTube in the context of patient education, the Global Quality Scale (GQS) has been commonly used (17,26). This scale was specifically designed to assess the quality of information aimed at patients. However, the present study aimed to evaluate the quality and reliability of YouTube videos not only for patients, but also for professionals, dentists, and dental students. Therefore, we employed the Global Score for Educational Value (GSEV), a scale closely adapted from GQS by Fischer et al. (21).

The mDISCERN score was originally developed by Singh et al. (17) to assess reliability, bias, clarity, reference citation, and the presence of potentially misleading information in YouTube videos (27). This scoring system has since been widely used to evaluate the reliability of online video content (26). For these reasons, both GSEV and mDISCERN were utilized in the present study to ensure a comprehensive evaluation of educational quality and reliability.

The overall educational value, as measured by the Global Score for Educational Value (GSEV), was moderate, with only a small percentage of videos classified as having good or excellent quality.

The mDISCERN tool, which assesses the reliability of health-related content, revealed lower average scores, indicating limited transparency, source citation, and comprehensiveness. The average mDISCERN score of 2.44

shows that the videos were generally of low reliability. None of the evaluated videos met the fourth and fifth criteria of mDISCERN, which assess the inclusion of alternative source options and acknowledgment of areas of uncertainty. While the mDISCERN scale provides a structured approach to evaluating reliability, its criteria may not fully align with the informal, visually driven nature of YouTube videos. Therefore, reliance on this tool alone could be seen as a methodological limitation in the context of evaluating open-access, user-generated content.

A statistically significant moderate positive correlation was found between video length and GSEV scores, indicating that longer videos tended to provide more comprehensive educational content. However, the weak correlation between GSEV and mDISCERN scores suggests that longer or more detailed videos are not necessarily more reliable.

Additionally, although video segments from television programs had slightly higher average GSEV scores than other sources, this difference was not statistically significant, implying that source alone may not determine educational quality. Although our study did not directly assess the impact of video content on viewer learning outcomes or clinical behavior, it is plausible that such content plays a substantial role especially for dental students and general practitioners who use YouTube informally for education. Case-based videos prepared by endodontists often demonstrated the use of chemical solvents during retreatment, and many clinicians opted for high-quality rotary or reciprocating files operating at high RPMs rather than dedicated retreatment systems. This may reflect advanced expertise or personal preference but also risks influencing viewer tendencies. The consistent use of rubber dam isolation further underscores their educational value. These videos, therefore, serve not only to display clinical techniques but may also affect decision-making in practice. One limitation of this study is that it focused only on the presence or absence of 13 predefined content categories, without evaluating the depth or scientific accuracy of the material. For example, although “success criteria” were mentioned in 45.7% of videos, the quality of the explanations was not assessed. Still, it is notable that most videos (57.1%) were uploaded by endodontists, with 8.6% coming from universities and 14.3% from private clinics employing specialists, suggesting a degree of professional reliability. Another limitation lies in the evaluator profile: two residents with two years of experience conducted the assessments. Although expert guidance was sought when needed, the absence of formally specialized reviewers may have influenced scoring.

Overall, these findings suggest that while YouTube videos on retreatment may offer basic visual support, they are generally not sufficient as educational resources, especially for students or patients seeking reliable information.

Conclusion

This study demonstrates that YouTube videos on endodontic retreatment often lack consistency and depth in presenting essential clinical information. Given the increasing reliance on online platforms for dental education and patient awareness, the variability in content quality underscores the importance of guiding viewers toward accurate and comprehensive resources on retreatment procedures.

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Conflict of Interest: We declare that we have no conflict of interest related to this study.

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Informed consent: Not applicable.

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ORIGINAL ARTICLE

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Youtube as a source of information about symptomatic irreversible pulpitis: Quality and content analysis

Mevlüt Sinan Ocak, Betül Yılmaz

Department of Endodontics, Firat University Faculty of Dentistry, Elazig, Türkiye

Purpose: With the advancement of technology, both patients and healthcare professionals increasingly seek information. However, analysis of the data hosted by various platforms that allow rapid access to such information via the internet remains underexplored. This study aims to evaluate the content accuracy and educational quality of YouTube videos related to symptomatic irreversible pulpitis.

Methods: On April 5, 2024, a search was conducted on the YouTube platform using the keyword "Symptomatic irreversible pulpitis." Initially, 610 videos were screened, but only 32 met the inclusion criteria. The videos were assessed according to five content parameters: Diagnosis, treatment, etiology, prognosis, and symptoms. Quality assessment was conducted using the Video Information and Quality Index (VIQI), which includes information flow, accuracy, technical quality, and title-content consistency. Kruskal-Wallis and Dunn's tests were used for statistical evaluations. (significance level $p<0.05$).

Results: Among the 32 videos included in the study, 34.4% provided inadequate, 43.8% moderate, and 21.9% high-quality information. Videos providing moderate-quality information had a significantly higher number of likes compared to the other groups ($p<0.05$).

Conclusion: Most YouTube videos related to symptomatic irreversible pulpitis are academically insufficient. There is a growing need for more reliable and higher-quality digital content to be used in dental education.

Keywords: Information; irreversible pulpitis; YouTube.

Introduction

Pulpitis is an inflammatory condition of the pulp tissue in response to stimuli and bacterial by-products. If the irritant is removed, the inflammation is considered reversible; however, if the irritant persists, it progresses to stages regarded as irreversible. The condition of the pulp is classified as healthy pulp, reversible pulpitis, symptomatic irreversible pulpitis, asymptomatic irreversible pulpitis, pulp necrosis, previously treated, and previously initiated therapy. This classification is based on histological and clinical changes in the pulp (1).

The clinical diagnosis of either reversible or irreversible pulpitis in a healthy pulp relies on past and current clinical signs and symptoms, the extent of caries near the pulp, responses to percussion and pulp tests, and the radiographic appearance of periapical tissues (2).

Symptomatic irreversible pulpitis is a condition based on subjective and objective findings, where the vital inflamed

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Correspondence: Mevlüt Sinan Ocak. Firat University, Faculty of Dentistry, Department of Endodontics, Elazig, Türkiye
Tel: +90 533 – 723 54 63 e-mail: msocak@firat.edu.tr
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pulp is incapable of healing, and root canal treatment is indicated (3). Its features include sharp pain after thermal stimuli, prolonged pain (usually lasting 30 seconds or more after stimulus removal), spontaneous (unprovoked) pain, and referred pain. Common etiologies include deep caries, extensive restorations, or fractures exposing the pulp tissue (4). Since inflammation has not yet reached the periapical tissues, percussion usually does not elicit pain or discomfort (5). Therefore, diagnosing teeth with symptomatic irreversible pulpitis is challenging. In such cases, the patient's history and thermal tests are used to assess pulpal status (6).

Clinicians with many years of experience often need to consult various resources to stay up to date. In recent years, there has been an increase in internet use by both healthcare professionals and patients seeking health information (7). Although there are various online resources for health-related information, 77% of online health seekers reportedly use general search engines like Google, Bing, and Yahoo, whereas only 13% utilize expert websites such as WebMD (8). In different studies, YouTube™ has been ranked as the top choice after Google and Facebook for online health-related searches (9,10).

Founded in 2005, YouTube is a free video-sharing website accessible to anyone with an internet connection. Users can view, like, comment on, and share videos, and upload original content without prior review or moderation (11). Because anyone can upload content without oversight, health-related videos may be uploaded by non-professionals, commercial entities, or doctors. As a result, these videos may contain insufficient or incorrect medical information, highlighting the need for critical evaluation.

In recent years, studies evaluating dental content on YouTube have revealed that a considerable portion of videos lack scientific accuracy and fail to meet educational standards. For example, videos related to endodontic procedures often present outdated or incomplete information, raising concerns about their reliability as educational tools for both patients and professionals (12-15). These findings emphasize the need to systematically analyze the quality and credibility of online video content in dentistry.

The aim of this study is to evaluate the accuracy and quality of YouTube videos related to symptomatic irreversible pulpitis. In the present study, the focus is exclusively on symptomatic irreversible pulpitis due to its clinical relevance and diagnostic complexity, as it represents a critical condition that necessitates root canal treatment and often leads patients to seek information online.

Materials and Methods

Video Selection

Since the data used in this study were obtained from a publicly available platform, ethics committee approval was not required. The search terms were selected based on terminology commonly used by dental students and clinicians on social media. A search for the term "symptomatic irreversible pulpitis" was conducted on YouTube™ on April 5, 2024. The results were sorted using the "sort by relevance" option, with no additional filters applied.

A total of 610 videos were identified through the search. Videos were excluded from the study if they met any of the following criteria: Not in English, advertisements, audio-only or visual-only content, unrelated to the search terms, or exceeding 20 minutes in length.

Video Evaluation

Out of the 610 videos reviewed, 32 met the inclusion criteria (Fig. 1). For each of these videos, the following were recorded: 1) Duration, 2) number of views, and 3) number of likes. Each video was evaluated for the presence of five content parameters: 1) Diagnosis, 2) treatment, 3) etiology, 4) prognosis, and 5) symptoms.

Each video was then scored based on the inclusion of information on these parameters: A score of 1 was assigned if the parameter was addressed, and 0 if it was not. Videos scoring 0–2 points were considered to provide insufficient information, those scoring 3–4 points were deemed to have moderate content (useful but with some deficiencies), and those scoring 5 points were classified as providing good information (comprehensively addressing all parameters).

The quality of the videos was assessed using the Video Information and Quality Index (VIQI), which includes four evaluation criteria: Information flow (relevance and coherence of the content) (VIQI 1), information accuracy (VIQI 2), quality (presence of images, animations, interviews, subtitles, and summaries) (VIQI 3), and precision (consistency between the video title and content) (VIQI 4). Each criterion was evaluated using a 5-point Likert scale (12).

Statistical Analysis

The statistical evaluations were performed in the SPSS software program (Version 22.0, IBM Corp, Armonk, NY, USA). The normality of data distribution was assessed using the Kolmogorov-Smirnov test, which revealed that the data did not follow a normal distribution. Descriptive statistical methods (minimum, maximum, mean, standard deviation, median, frequency) were used for data analysis. The Kruskal-Wallis test was applied to compare quantitative variables and intergroup differences. When significant differences were found, Dunn's test was used to identify the specific group responsible for the difference. A p-value of less than 0.05 was considered statistically significant.

Results

Among the 610 videos screened, only 32 met the inclusion criteria. Of the included videos, 75% contained information related to diagnosis, 53.1% to treatment, 46.9% to etiology, 46.9% to prognosis, and 87.5% to symptoms. Overall, 34.4% of the videos provided insufficient information, 43.8% offered moderate-level information, and 21.9% were rated as having good informational content (Table 1). Descriptive statistics of the videos are presented in Table 2.

Videos providing moderate-level information had a significantly higher number of likes compared to both the insufficient and good information groups ($p=0.045$ and $p=0.021$, respectively; $p<0.05$). No significant difference was observed between the insufficient and good groups in terms of like counts ($p=0.559$; $p>0.05$). (Table 3; Fig. 1)

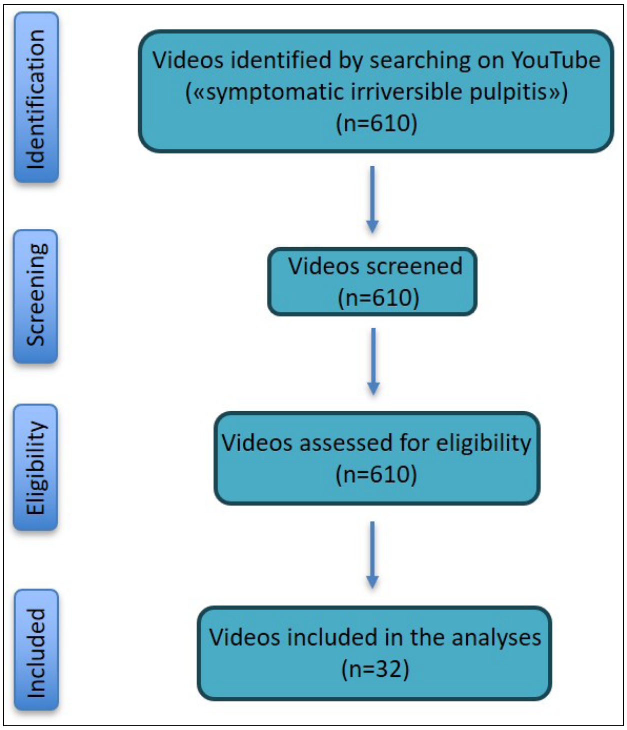

Fig. 1. Flowchart showing the evaluation process of the YouTube videos examined in the study.

Table 1. Descriptive data on the informational capacity of the videos

	Minimum	Maximum	Mean±SD	Median
Information capacity score	0	5	3.09±1.49	3
	n	%		
Diagnosis	24	75.0		
Treatment	17	53.1		
Etiology	15	46.9		
Prognosis	15	46.9		
Symptoms	28	87.5		
Information capacity				
Inadequate	11	34.4		
Medium	14	43.8		
Good	7	21.9		

Table 2. Descriptive statistics of the videos

	N	Minimum	Maximum	Mean±SD	Median
Video Duration (min)	32	1:36	19:2	9.61±4.89	8.76
Views	32	9	50262	4198.38±11110.39	753
Likes	32	1	2100	127.59±400.34	15
VIQI 1 "Information Flow"	32	2	5	3.78±0.83	4
VIQI 2 "Information Accuracy"	32	4	5	4.56±0.50	5
VIQI 3 'Quality'	32	2	5	3.72±0.89	4
VIQI 4 "Accuracy"	32	3	5	4.13±0.71	4
VIQI Total	32	11	20	16.19±2.49	16

VIQI: Video Information and Quality Index.

Table 3. Comparisons by level of informational content

	Inadequate Mean±SD (median)	Min-Max	Medium Mean±SD (median)	Good Min-Max	Mean±SD (median)	Min-Max	p
Video Duration (min)	8.79±4.81 (8.3)	2.39-16.39	11.32±4.73 (12.7)	1.36-19.2	7.48±4.79 (6.5)	2.58-14.44	0.334
Views	5178.91±14973.66 (292)	9-50262	5175.86±10631.97 (1709)	75-41055	702.57±962.13 (308)	28-2795	0.080
Likes	206.36±628.49 (9)	1-2100	123.64±256.47 (48)	4-992	11.71±11.93 (7)	1-33	0.036*
VIQI 1	3.64±0.92 (4)	2-5	4.07±0.62 (4)	3-5	3.43±0.98 (3)	2-5	0.197
VIQI 2	4.45±0.52 (4)	4-5	4.71±0.47 (5)	4-5	4.43±0.53 (4)	4-5	0.322
VIQI 3	3.64±1.03 (4)	2-5	3.86±0.66 (4)	3-5	3.57±1.13 (4)	2-5	0.901
VIQI 4	3.91±0.7 (4)	3-5	4.29±0.73 (4)	3-5	4.14±0.69 (4)	3-5	0.407
VIQI Total	15.64±2.84 (16)	11-20	16.93±1.82 (16.5)	15-20	15.57±3.05 (15)	11-20	0.384

Kruskal Wallis Test. *p<0.05. VIQI: Video Information and Quality Index.

Discussion

In dental and endodontic treatment processes, patients' knowledge about the procedure and their compliance are crucial factors for achieving successful clinical outcomes. In this context, video-sharing platforms such as YouTube have become significant sources of information for both patients and experienced clinicians (16). Studies have shown that YouTube is a highly effective medium for disseminating medical and dental information (17).

During the COVID-19 pandemic, dental students were distanced from traditional learning methods and had to resort to online educational tools such as virtual reality, communication platforms, lectures, presentations, hands-on and virtual workshops, webinars, and didactic courses (18). During this period, YouTube and similar online streaming platforms stood out as important resources for distance learning due to the powerful impact of audiovisual content on cognition and emotion (19).

However, despite YouTube's wide content range, it has been observed that some educational videos fail to reflect updated diagnostic criteria and treatment approaches or include misleading information (20). Although YouTube was not originally designed as an educational platform, its ease of access and popularity have made it a frequent subject of academic evaluation concerning the reliability of scientific content.

Due to the nature of YouTube, the information in the videos published on the platform is not subject to academic review and is not pre-verified by specialists in the field. Consequently, videos on symptomatic irreversible pulpitis in endodontics often fall short of providing comprehensive coverage. This study evaluated the accuracy, reliability, and quality of YouTube videos on symptomatic irreversible pulpitis. The findings revealed that these videos were generally insufficient in educational quality.

Previous studies have also investigated YouTube's role in dental education. For instance, Kaval et al. (12) reported that most YouTube videos on regenerative endodontic procedures focused mainly on clinical practices but lacked academic depth. Similarly, another study on vital pulp therapy reported that content on YouTube had low reliability and often included incomplete information (13).

Additionally, a study on root resorption and related etiological factors found that most YouTube videos were insufficient in content and were predominantly uploaded by dental clinics. It was noted that approximately 57.9% of the videos were of low quality, and only 2.1% met academic standards (14). This highlights a significant gap in educational quality in dental training.

Another study on the use of mineral trioxide aggregate (MTA) found that the majority of YouTube content was uploaded by commercial companies or individual users, and the information presented often lacked scientific accuracy (15). The insufficient availability of academic-level content can lead to the widespread dissemination of misleading information among students and clinicians.

Our study also identified specific deficiencies in the content of dental videos on YouTube. For instance, prognosis and etiology were the least addressed topics. Other studies similarly found that videos related to endodontic treatments often lacked detailed discussion of etiology, diagnosis, and prognosis (14,15). This reflects a significant shortcoming in dental education and underscores the need for greater academic content production. The findings of our study support this conclusion, demonstrating that the educational value of videos on symptomatic irreversible pulpitis is generally low.

One of the methodological limitations of this study is the use of the VIQI index, which relies on subjective interpretation by the evaluators. Although this tool has been validated in previous studies assessing the quality of online health information, such as those focusing on regenerative endodontics and vital pulp capping (12,13), the scoring may still vary based on the evaluators' clinical experience and personal judgment. In the present study, two independent evaluators with expertise in endodontics applied the VIQI criteria based on a standardized scoring guideline. Any discrepancies in scoring were resolved through consensus, which aimed to minimize individual bias and improve the overall reliability of the results.

Another important finding of our study is the statistical difference in the number of likes and views among videos with different levels of information. Videos offering moderate-level information received more likes than both low-quality and high-quality videos. This suggests that viewers may prefer general and easily understandable content over highly academic and detailed materials. A similar trend was observed in a study on the use of mineral trioxide aggregate (MTA), where academic content created by experts received less attention, whereas videos with practical applications attracted more engagement (15).

This study has some limitations. First, the video selection was based solely on a specific keyword search, resulting in a limited dataset. Moreover, due to the ever-changing nature of YouTube algorithms, the results may vary over time. Our study only analyzed videos in English; a comprehensive analysis of content in other languages was not performed. Another limitation of this study is that it only included English-language videos. YouTube hosts a diverse range of content in numerous languages, and the informational quality may vary across different linguistic and cultural contexts. Future research should consider evaluating videos in multiple languages and regions to provide a more inclusive and comprehensive assessment of dental information available online. Such efforts could help identify region-specific gaps in educational content and facilitate the development of targeted and culturally appropriate digital resources to support global dental education.

Conclusion

The findings of this study reveal that most YouTube videos concerning symptomatic irreversible pulpitis are academically insufficient and lack reliable academic sources. These results underscore the need to increase the production of high-quality digital content in the field of dentistry and to implement monitoring mechanisms for existing materials.

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Ethical Approval: Ethics committee approval was not required because publicly available data were used for this study.

Informed consent: N/A

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ORIGINAL ARTICLE

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The effect of different irrigation activation procedures on the penetration of a contrast irrigation solution into lateral canals of 3D-printed tooth models

Melisa Uslu, Nazife Maide Dayican, Sevinc Aktemur Turker

Department of Endodontics, Zonguldak Bülent Ecevit University Faculty of Dentistry, Zonguldak, Türkiye

Purpose: The aim of this study was to compare the effectiveness of the XP-Endo Finisher R (XPFR), sonic irrigation (EDDY) and manual dynamic activation (MDA) in enhancing the penetration of a contrast irrigation solution into the lateral canals of 3D printed teeth.

Methods: A total of 45 3D-printed teeth with lateral canals 3 mm from the root apex were used in this study. Root canals were prepared up to size #35.06. The specimens were then divided into three groups (n=15) according to the irrigation activation technique used: XPFR, EDDY and MDA. Each technique was applied using 1.5 mL of 1% methylene blue (MB) as the contrast dye. Penetration depth was assessed via images captured under a dental microscope, and scored on a four-point scale. Data analysis was performed using Kruskal-Wallis and Mann-Whitney U tests, with statistical significance set at $p<0.05$.

Results: Statistical analysis revealed significant differences among the groups ($p=0.002$). In the XPFR group, penetration of MB into the lateral canals was lower than in the EDDY ($p=0.002$) and MDA ($p=0.008$) groups.

Conclusion: EDDY and MDA techniques were more effective than XPFR in facilitating MB penetration into lateral canals of 3D-printed models.

Keywords: 3D-printed teeth; irrigant penetration; manual dynamic activation; sonic irrigation; XP-Endo Finisher R.

Introduction

The root canal system has a complex anatomy, especially in the apical third (1). This is because anatomical variations such as isthmuses, lateral and accessory canals and apical deltas are more common in this region (2). These anatomical complexities make it more difficult to clean the apical third of the root canal system. De Deus has reported that lateral canals tend to be concentrated in the apical region, making them particularly difficult to reach with standard irrigation protocols. Their narrow diameter and variable positioning limit access, thereby complicating the thorough removal of tissue debris and microbial contaminants (3).

In an effort to improve irrigant delivery into anatomically complex regions of the root canal system, several activation techniques have been introduced. These approaches

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Correspondence: Nazife Maide Dayıcan. Department of Endodontics, Faculty of Dentistry, Zonguldak Bülent Ecevit University, Zonguldak, Türkiye
Tel: +90 554 – 691 25 95 e-mail: maidedayican@gmail.com
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are designed to increase the depth of irrigant penetration and enhance the removal of residual debris and microorganisms (4). Techniques such as manual dynamic activation (MDA), sonic agitation (e.g., EDDY), and mechanical agitation using devices like the XP-Endo Finisher R have received growing attention for their potential to optimize irrigant efficacy in inaccessible areas. Manual dynamic activation (MDA) entails the use of a well-adapted gutta-percha cone, which is manually agitated within the canal in a push-pull motion to improve irrigant flow. This technique has been associated with enhanced smear layer removal in multiple studies (5-7). The XP-Endo Finisher R (XPFR) (FKG, La Chaux-de-Fonds, Switzerland) is a specialized instrument designed to enhance the removal of root canal filling materials, particularly in curved or oval-shaped canals, following conventional retreatment procedures. The MaxWire (Martensite Austenite Electropolish Flex, FKG, Dentaire) technology is used in this file system. XPFR improves the distribution of the irrigation solutions. According to the manufacturer, the XPFR is able to abrade the dentine walls and access irregular areas while maintaining the original anatomy of the root canals. It can be used as an adjunct to the final step with any file system with a diameter of #30 or larger (5). It has also been used as a complementary approach to irrigation procedures in teeth with complex anatomy, such as oval root canals. (6). One of the sonic irrigation activation systems, EDDY (VDW, Munich, Germany), consists of a flexible polyamide tip (size #25.04). It is connected to an air scaler operating at 6 kHz. This system produces vigorous fluid agitation and has demonstrated efficacy in lowering bacterial counts (7), promoting tissue dissolution more effectively than passive ultrasonic irrigation (PUI) (8), and improving debris removal from root canals (9).

3D-printing is well established in dentistry and recently has been integrated into modern endodontics. It has been utilized to create various models for both educational and research purposes, such as comparing the different rotary instruments (10), obturation techniques (11) and various irrigation methods (12). Currently, various 3D printing technologies based on distinct principles, including Selective Laser Melting (SLM), Selective Laser Sintering (SLS), Fused Deposition Modeling (FDM), Stereolithography (SLA), Digital Light Processing (DLP), have been extensively studied and implemented in the field of dentistry. SLA printing is particularly advantageous in creating dental models, Among the commonly employed materials in dental 3D printing, photopolymer resins stand out due to their ability to undergo precise photopolymerization when exposed to specific wavelengths of light. These resins are primarily utilized in SLA printers, a technology that enables the fabrication of high-resolution, intricate models with excellent dimensional accuracy (13).

A review of the existing literature reveals a lack of studies directly comparing the influence of XPFR, EDDY and MDA techniques on the depth of irrigation solution penetration into lateral canals. The in vitro study was designed to evaluate and compare the penetration efficiency of a contrast dye into the lateral canals of standardized 3D printed root canal models of three applied activation methods. The study was conducted under the null hypothesis that no statistically significant differences would exist in penetration depth among the evaluated techniques.

Materials and Methods

A total of 45 transparent and radiopaque 3D-printed maxillary lateral incisor models were fabricated by a commercial provider (Ancorax Software and Medical Devices, Ankara, Türkiye). The sample size of the study was calculated with reference to the study conducted by Gregorio et al. (14), Spoorthy et al. (15) and Andrade-Junior et al. (16). All root canals were standardized to a length of 22 mm, with a 0.06 taper and an apical diameter of 0.30 mm. Each model included a lateral canal 3 mm in length and 0.15 mm in diameter, positioned 3 mm coronally from the apical terminus of the main canal (Fig. 1).

Prior to the experimental procedure, the teeth were embedded in polyvinyl siloxane impression material (Hydrise Light, Zhermack, Italy) to mimic periodontal support and clinical conditions.

Root Canal Preparation

The working length was established as 1 mm short of the full canal length. The root canal instrumentation was shaped with EndoArt Touch Gold (Inci Dental Productions Co, İstanbul, Türkiye) rotary files up to size #35/0.06 in accordance with the manufacturer's recommended protocol. During the shaping procedures, canals were irrigated with distilled water. After completion of the instrumentation, the patency of the main and lateral root canals was confirmed with a #10 K-file.

The teeth were allocated into three groups based on the irrigation activation technique employed (n=15). A 1% methylene blue solution (Sigma-Aldrich, Steinheim, Germany) was used as a contrast irrigating solution (CIS) to assess the depth of penetration, in accordance with a previously published study (17). The root canals were filled with the 1% methylene blue solution and subsequently subjected to activation using three different methods: XPFR, EDDY, and MDA.

- Group XPFR: The 1% methylene blue applied to the ca-

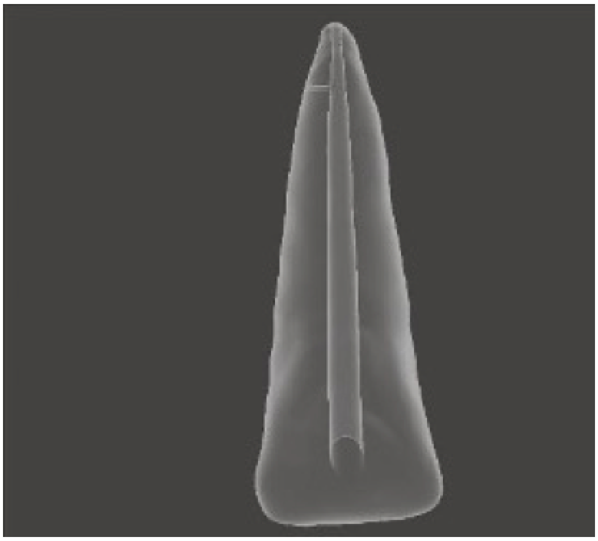

Fig. 1. Construction of transparent 3D printed dental models using digital design technologie.

nals was activated with an XPFR file with a torque of 1 N-cm at 800 rpm along the WL. XPFR was applied in 7-8 mm up and down movements according to the manufacturer's instructions.

• Group EDDY: A size 25/.04 EDDY polyamide tip was inserted 2 mm short of the working length and connected to a TA-200 air scaler (Micron, Tokyo, Japan). Sonic activation was applied for 60 seconds at a frequency of 6 kHz.

• Group MDA: A 35/.06 gutta-percha (Dentsply, Maillefer, Ballaigues, Switzerland) was applied with an amplitude of 2 mm in up and down movements at a frequency of 100 strokes for 60 s, 1 mm shorter than the working length used in a previous study (18).

Visual Assessment Protocol

Upon completion of the irrigation procedures, each sample was observed under a dental operating microscope, and images were captured in JPEG format. All lateral canals were measured and transferred to ImageJ software (National Institutes of Health, Bethesda, USA). The depth of irrigation penetration into the lateral canal was scored using the following scoring system (19) (Fig. 2): Score 0: Lateral canal was empty, score 1: Contrast irrigation solution penetrated less than half of the lateral canal, score 2: Contrast irrigation solution penetrated more than half of the lateral canal, score 3: Contrast irrigation solution was observed to completely fill the lateral canal.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics software (version 29.0). Normality of data distribution was assessed using the Shapiro-Wilk test. Comparisons between groups were made using the Kruskal-Wallis and Mann-Whitney U tests. A p-value less than 0.05 was considered statistically significant.

Results

Table 1 shows the mean and standard deviation values of the groups. Statistical analysis revealed a significant difference between the irrigation activation techniques ($p=0.002$). In the XPFR group, the depth of penetration of the MB into the lateral canal was significantly less than in the EDDY ($p=0.002$) and MDA ($p=0.008$) groups. However, no significant difference in CIS penetration depth was observed between the EDDY and MDA groups ($p=0.595$).

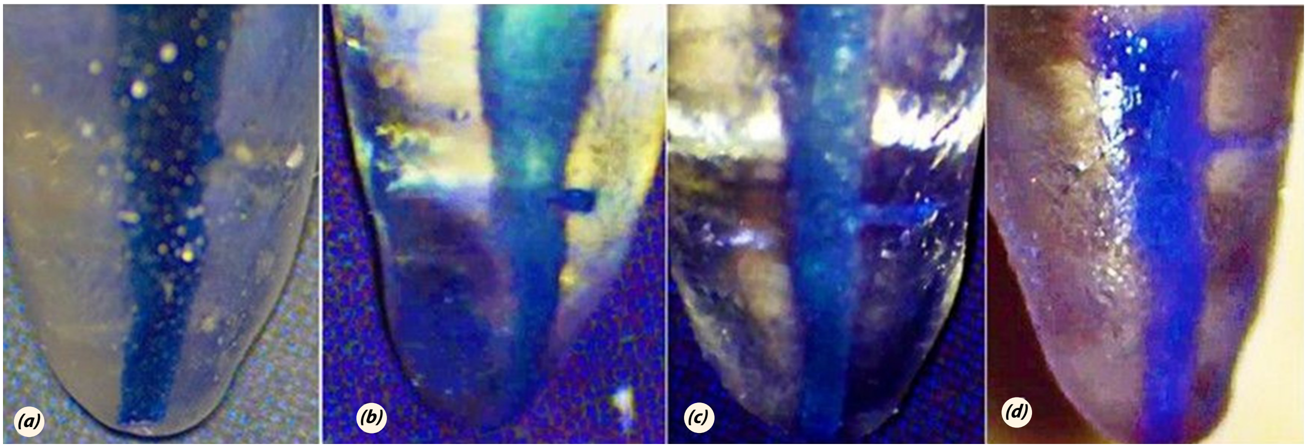

Fig. 2. Scoring System: **a-0:** Lateral canal was empty, **b-1:** Less than half of the lateral canal was filled with the contrast irrigation solution, **c-2:** Contrast irrigation solution covered more than half of the lateral canal, **d-3:** Contrast irrigation solution was observed to completely fill the lateral canal.

Table 1. Mean and standard deviation values of penetration scores of contrast irrigation solution in experimental groups

Irrigation Activation Techniques	Mean ± Standard Deviation
XP-Endo Finisher R	1.5333a±0.64
Manuel Dynamic Irrigation	2.4000b±0.83
EDDY	2.5333b±0.92

*p=0.002, Superscript letters indicate statistically significant differences between groups. (Mann Whitney U Test)

Discussion

Lateral canals, which often exit at various points along the root surface, serve as potential pathways for microbial invasion and may contribute to the development of apical periodontitis. Therefore, ensuring adequate disinfection of these anatomical extensions is particularly crucial in cases involving pulp necrosis or periapical infections. However, due to their narrow structure and complex positioning, achieving effective cleaning and decontamination of lateral canals remains a significant challenge (20).

In this study, resin blocks with simulated lateral canals were used to standardise the anatomy. Since it was not possible to create root canals with standardised dimensions due to variations in natural teeth, resin blocks were preferred. Previous studies have also shown that it is useful to use simulated artificial root canals to study irrigation efficacy (21-23). However, the use of simulated root canals has inherent limitations when compared to natural root canals, mainly because they do not replicate the dentin structure and the complex root canal morphology.

To address this, modern irrigation strategies have focused on enhancing irrigant distribution and penetration using activation techniques. Several studies have assessed the depth of irrigation solution penetration into lateral canals to evaluate the cleaning efficacy of different activation systems (16,24-26). Despite these investigations, comparative data on XPFR, EDDY, and MDA methods have remained scarce. Thus, the present in vitro study aimed to provide insight into how these three techniques influence irrigation solution penetration into simulated lateral canals within 3D-printed tooth models. Penetration was quantified using a direct visual scoring approach under magnification, following the protocol described by Fidan and Erdemir (25), who concluded that direct observation provided the most accurate assessment when compared to radiographic or tomographic imaging techniques.

In the current study, the XP-Endo Finisher R exhibited significantly less irrigation solution penetration into lateral canals than both the EDDY and MDA techniques. Therefore, the null hypothesis was rejected. While no prior research has directly evaluated XPFR in this specific context, a related investigation comparing the older XP-Endo Finisher with EDDY and laser-activated irrigation showed comparable results for the two techniques in terms of penetration at the 2 mm level of root canals (25). The lower performance of XPFR in the present study may be attributed to its direct contact with dentinal walls, particularly in the apical region. This contact may limit its oscillation and reduce the dynamic flow of irrigation solution, despite its high displacement amplitude.

The penetration depths achieved by EDDY and MDA were statistically similar, suggesting comparable performance. Although direct comparisons between these two techniques are limited, Donnermeyer et al. (24) evaluated their efficacy in hydrogel removal within curved canals and reported superior outcomes with EDDY. The discrepancies between the findings are likely due to the use of a different experimental methodology in that study. While their study focused on the removal of hydrogel from lateral canals in root canals with a 60-degree curvature, our study investigated the amount of irrigant penetration into lateral canals in straight root canal. Conversely, studies comparing MDA with other sonic activation devices such as the EndoActivator have produced controversial findings. Virdee et al. (27) found that MDA achieved greater penetration of sodium hypochlorite into dentinal tubules than both passive ultrasonic irrigation and the EndoActivator. In that study, the authors investigated the penetration of the irrigant into dentinal tubules in extracted teeth. In contrast, Solete et al. (28) observed inferior irrigant penetration with MDA in the apical third compared to sonic activation. In that study, the penetration of the irrigation solution into the apical region of extracted teeth was evaluated using radiological methods.

Alsubait et al. (29) in their study in which they investigated the removal of debris using EDDY, MDA and XPFR activation techniques, they found that the MDA technique was more unsuccessful than EDDY and XPFR methods. It is thought that the results of this study are different from our results due to the examination of mandibular molar teeth and the use of natural teeth instead of resin block teeth.

3D-printed tooth replicas were used in the current study under in vitro conditions. The use of 3D-printed tooth models, which have been employed in several research studies (11,12,15,18,30-32), offers a significant advantage by standardizing the dimensions of lateral root canals. This standardization enables more reproducible comparisons of different irrigation techniques, a level of consistency that is difficult to achieve with extracted teeth. While this approach allows for reproducibility and consistent morphology, it does not fully replicate the anatomical variability of natural teeth, including features like apical deltas and complex lateral canal networks. Additionally, under the clinical conditions, the wettability of dentine, its surface energy, and the use of sodium hypochlorite may influence the penetration of irrigation solutions into the lateral canals. However, this experimental method is designed to measure how effectively irrigation activation techniques can mechanically deliver the solution into the lateral canal. Nonetheless, such models offer a reliable platform for comparative analysis of irrigation methods under uniform conditions.

Conclusion

The present study results suggest that EDDY and MDA demonstrated superior efficacy compared to XPFR in delivering the contrast irrigation solution into lateral canals. These results emphasize the importance of the irrigation activation method in enhancing irrigant distribution within anatomically complex regions of the root canal system. Further studies involving natural teeth and clinically relevant conditions are recommended to validate these outcomes.

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Informed consent: As this was an in vitro study utilizing 3D-printed models, formal informed consent was not required.

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ORIGINAL ARTICLE

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Evaluation of periapical lesion healing in mandibular molars with chronic apical periodontitis after initial root canal treatment and retreatment at 2-year follow-up using fractal analysis: A retrospective study

Kübra Gürler,[1] Berkhas Tumani Üstdal,[2] Koray Yılmaz[1]

[1]Cukurova University, Department of Endodontics Faculty of Dentistry, Adana, Türkiye
[2]Fatma Kemal Timuçin Dental Hospital, Adana, Türkiye

Purpose: The aim of this retrospective study was to evaluate the degree of healing in the periapical region of teeth with chronic apical periodontitis (CAP) following initial root canal treatment (RCT) and retreatment using fractal analysis (FA) of panoramic radiographs after 2-year follow-up.

Methods: This study included a total of 136 mandibular molars, 71 initial RCTs and 65 retreatments. Teeth that were diagnosed with CAP and presented with a well-defined radiolucent periapical lesion were included in the study. Both preoperative and 2-year follow-up radiographs of ideal quality were chosen for the analysis. FA was performed using the box-counting method proposed by White and Rudolph using ImageJ 1.3 software (NIH, Bethesda, MD, USA). The data were analyzed using the Kolmogorov–Smirnov, Wilcoxon, and Chi–square tests and Spearman's correlation coefficient.

Results: No statistically significant difference was found between the healing rates of the initial RCT and retreatment procedures ($p>0.05$). There was a statistically significant difference between the fractal dimension values measured before treatment and 2 years after treatment in patients who underwent initial RCT and retreatment procedures ($p<0.05$).

Conclusion: According to the FA results, the healing rate in the periapical region was similar between the initial RCT and retreatment procedures.

Keywords: Apical periodontitis; fractal analysis; initial root canal treatment; periapical healing; retreatment.

Introduction

Apical periodontitis (AP) is an inflammatory disease of periapical tissues characterized by bone destruction in the periradicular region resulting from microbial infection within the pulp (1). Depending on the condition of the infection within the root canal, the inflammatory reaction may be either acute or chronic (2). In chronic apical periodontitis (CAP), the affected tooth is asymptomatic, and if this inflammation in the periapical tissues remains untreat-

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Correspondence: Kübra Gürler. Cukurova University, Department of Endodontics Faculty of Dentistry, Adana, Türkiye
Tel: +90 505 – 116 55 26 e-mail: gurlerkubra@hotmail.com

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ed, bone destruction typically progresses gradually (3).

The etiological spectrum and treatment options for CAP differ between teeth that have not undergone root canal treatment (RCT) and those that have been previously treated with RCT (4). In teeth without prior RCT, potential causes of CAP include the progression of caries into the pulp, leading to microbial invasion, pulp necrosis, and the spread of inflammation to periapical tissues; the colonization of pulp tissue by microorganisms in cases where the pulp loses its blood supply due to trauma; and the development of pulp necrosis and subsequent periradicular pathology in situations where the pulp tissue is exposed due to dental wear (5).

The fundamental treatment steps for CAP involve the removal of intraradicular microorganisms through chemomechanical preparation to significantly reduce the microbial load and prevent reinfection with well-sealed root canal filling (6). Periapical lesion healing following RCT typically occurs through hard tissue regeneration, which is a reduction in radiolucency in the periapical region on follow-up radiographs (7). Although initial RCT has a high success rate reaching 89%, failure may occur over time following treatment. In teeth that have undergone RCT, reinfection can occur due to inadequate aseptic control, missed canals, insufficient instrumentation, inefficient irrigation, or leakage of temporary or permanent restorations, which can similarly trigger a periapical immune response (8). In cases where the initial RCT fails, retreatment is considered the first option, as it is cost-effective and provides satisfactory outcomes (9,10). The success rate of retreatment ranges between 64% and 91% (11).

To evaluate AP healing, clinical and radiographic follow-up at regular intervals is needed over a minimum observation period of 1 year following RCT (12). Dental radiographs are routinely employed to assess root canal treatment outcomes, track postoperative healing, and detect changes in bone density (13). The Brynolf criteria, Rud method, and periapical index (PAI) are subjective assessments used to evaluate radiographic changes in periapical tissues (14-16). Quantitative approaches, such as measuring bone density and analyzing it using Hounsfield units (HUs), have been developed to address the issue of subjectivity in evaluating radiopacity changes in visually assessed apical lesion healing (17). Recent studies in the literature have shown that the trabecular microstructure of the bone should also be considered when evaluating bone density (17,18). The branched structure and self-similarity of trabecular bone, which are fractal properties, enable the use of fractal analysis (FA) to quantitatively evaluate the complex structure of trabecular bone (19) . FA is an analysis capable of quantitatively evaluating changes occurring in bone tissue. FA has been reported to be an adequate technique for identifying osteoporotic conditions in the jaw (20). Additionally, FA is widely used in radiographs to detect and evaluate changes in bone, apical healing, the periapical bone, and systemic conditions affecting the bone (21).

The aim of this retrospective study was to evaluate the degree of healing in the periapical region of teeth with CAP following initial RCT and retreatment procedures using FA on panoramic radiographs after 2-year follow-up. The null hypothesis (H_0) of this study is that there is no significant difference in periapical healing, as measured by fractal dimension (FD) values obtained through fractal analysis of panoramic radiographs, between initial RCT and retreatment in cases of CAP.

Materials and Methods

Sample Selection

Ethical approval for this retrospective study was obtained from the Cukurova University Research Ethics Committee (Meeting no: 144, Decision no: 30, Date: May 10, 2024) and the study was conducted according to the Helsinki Declaration. The medical, clinical, and radiographic data of patients who underwent initial RCT or retreatment between 2020 and 2022 at the Department of Endodontics, Faculty of Dentistry, Cukurova University, were evaluated. A total of 276 patient records were initially screened from the institutional archive. After applying the inclusion and exclusion criteria, 140 cases were excluded due to missing or poor-quality preoperative or 2-year follow-up panoramic radiographs, systemic conditions affecting bone metabolism, periodontal involvement, or incomplete documentation. Ultimately, 136 mandibular molars from patients who met all inclusion criteria and had complete radiographic records of diagnostic quality were included in the final analysis (Fig. 1).

Inclusion Criteria

- Patients aged 18–65 years without any systemic diseases or periodontal problems affecting bone metabolism.

- Mandibular molars diagnosed with CAP, presenting with a well-defined radiolucent periapical lesion of at least 2×2 mm in size and radiographically exhibiting intact marginal adaptation of the coronal restoration (Fig. 1)

Patients included in the study were selected from those whose initial RCTs or retreatments were completed by a single endodontist (K.G.).

Exclusion Criteria

- Teeth with open apices and requiring root canal filling with MTA

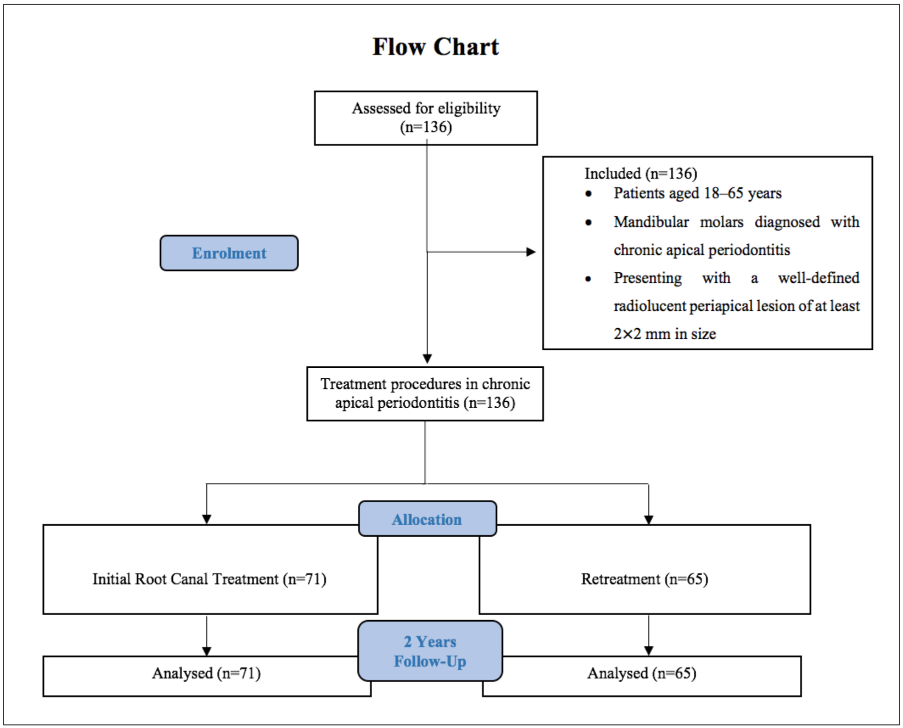

Fig. 1. The flowchartof participants throughout the trial.

- Teeth that have undergone surgical retreatment
- Patients with systemic diseases affecting bone metabolism or using medications related to bone metabolism
- Missing or poor-quality preoperative or 2-year follow-up panoramic radiographs
- Incomplete clinical or radiographic documentation

Sample Size Calculation

The sample size was calculated using power analysis (G*Power, ver. 3.1.9.2, Franz Faul; University of Kiel, Germany) on based a previous study (22), with 80% power, a 5% α error, and an effect size of 0.5. The minimum sample size was determined to be 50 teeth per group. The study was completed with a total of 136 teeth, including 71 initial RCTs and 65 retreatments, who had preoperative panoramic radiographs and 2-year follow-up radiographs and met the standards required for FA evaluation.

Initial RCT Procedures

All initial RCT procedures were performed at a single visit under magnification (3x loupe) and illumination. Local anesthesia was administered in both treatment modalities to ensure patient comfort during the placement of the rubber dam. The anesthesia technique utilized was the inferior alveolar nerve block. After the relevant tooth was anesthetized with 4% articaine hydrochloride with 1:100,000 epinephrine (Ultracain D-S; Sanofi, Paris, France), the tooth was isolated with a rubber dam. Any caries or coronal restorations present on the tooth were completely removed. An endodontic access cavity was prepared under water cooling using diamond round and fissure burs. The working length (WL) of the teeth was determined using a #10 K-type hand file and an electronic apex locator (VDW Gold; VDW, Munich, Germany), and periapical radiographs were taken to confirm the WL. After the WL was established, the root canals were irrigated with 2 ml of 2.5% sodium hypochlorite (NaOCl). A reproducible glide path was created using a #15 K-type hand file. The root canal shaping procedures were completed using the Reciproc Blue R25 file (25/.08) (RB, VDW, Munich, Germany). As the final irrigation solution, the root canals were irrigated sequentially with 2 ml of 2.5% NaOCl, 2 ml of 17% ethylenediaminetetraacetic acid (EDTA), and 2 ml of saline solution. After the root canals were dried with paper points, root canal obturation was performed using cold lateral condensation technique with gutta-percha and a root canal sealer (Adseal, Meta Biomed, Korea). The permanent restoration of the teeth was completed using composite resin (Clearfil Majesty Posterior, Kuraray Medical, Inc., Tokyo, Japan).

Retreatment Procedures

All retreatment procedures were performed at a single visit under magnification (3x loupe) and illumination. After the relevant tooth was anesthetized with 4% articaine hy-

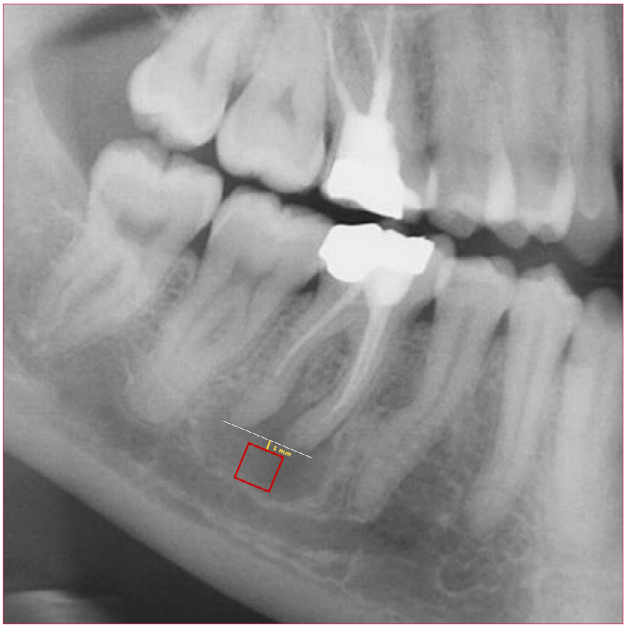

Fig. 2. Selection of the regions of interest (ROI) on the panoramic radiograph. The red square shows the ROI, the white line shows the root apex plane, and the yellow line indicates the distance between the ROI and the root apex plane.

drochloride with 1:100,000 epinephrine (Ultracain D-S; Sanofi, Paris, France), the tooth was isolated with a rubber dam. Any caries or coronal restorations present on the tooth were completely removed. An endodontic access cavity was prepared under water cooling using diamond round and fissure burs. Initial root canal fillings were removed using MicroMega Remover retreatment files (30/.07) (Coltene-Whaledent, Altstätten, Switzerland). The WL was determined using an electronic apex locator (VDW Gold; VDW, Munich, Germany), and periapical radiographs were taken to confirm the WL after the complete removal of the root canal filling. After the WL was established, the root canals were irrigated with 2 ml of 2.5% NaOCl. A reproducible glide path was created using a #15 K-type hand file. Root canal shaping was subsequently completed using Reciproc Blue R25 (25/.08) (RB, VDW, Munich, Germany) files for the mesial canals and Reciproc Blue R40 (40/.08) (RB, VDW, Munich, Germany) files for the distal canals. As the final irrigation solution, the root canals were irrigated sequentially with 2 ml of 2.5% NaOCl, 2 ml of 17% EDTA, and 2 ml of saline solution. After the root canals were dried with paper points, root canal obturation was performed using cold lateral condensation technique with gutta-percha and a root canal sealer (Adseal, Meta Biomed, Korea). Permanent restoration of the teeth was completed using composite resin (Clearfil Majesty Posterior, Kuraray Medical, Inc., Tokyo, Japan).

Radiography Protocol

Patients who had completed the initial RCT or retreatment procedures returned to the dental faculty hospital after 2 years for endodontic or other reasons and who had panoramic radiographs taken were selected for the study. Both preoperative and 2-year follow-up radiographs of ideal quality were chosen for image analysis. The actual follow-up duration was calculated individually based on the dates of the initial treatment and the follow-up panoramic radiograph. The mean follow-up time was 24.3±1.7 months, with a minimum of 22 months and a maximum of 28 months.

Coronal restorations were evaluated on panoramic radiographs to exclude teeth with gross defects. Only teeth with clearly intact proximal margins, without evidence of radiolucency, overhang, or marginal breakdown exceeding 0.5 mm, were included. All assessments were performed by a calibrated dentomaxillofacial radiologist under standardized conditions (high-resolution diagnostic monitor, consistent ambient lighting) to ensure reproducibility and minimize interobserver variability. The evaluation focused on the mesial and distal aspects of the restoration margins, where visibility is optimal in panoramic imaging.

Although periapical radiographs are generally preferred for the evaluation of periapical lesions and fractal analysis, this retrospective study included only patients who had returned to the faculty of dentistry for routine care, endodontic or other reasons and had panoramic radiographs of sufficient diagnostic quality. Standardized periapical images were not consistently available for all cases. Therefore, to maintain methodological consistency and reproducibility, only panoramic radiographs taken from the same digital unit under identical exposure parameters were used for FA.

Panoramic radiographs were obtained using a Planmeca ProMax (Helsinki, Finland) device with exposure parameters of 84 kilovolts (kVp), 16 milliamperes (mA), and a 14-second exposure duration.

Fractal Analysis

A dentomaxillofacial radiologist calculated the fractal dimension (FD) on each panoramic image. For both the pre- and postoperative radiographs, a 32×32-pixel region of interest (ROI) was placed 1 mm coronal to the radiographic apex (Fig. 2). The ROI was positioned at the same site on both images for each tooth to ensure standardization and reproducibility.

FA was performed using the box-counting method proposed by White and Rudolph (23) using ImageJ 1.3 software (NIH, Bethesda, MD, USA). First, the ROI was selected and copied (Fig. 3a). A Gaussian filter was applied to the image to create a blurred version (Fig. 3b). After

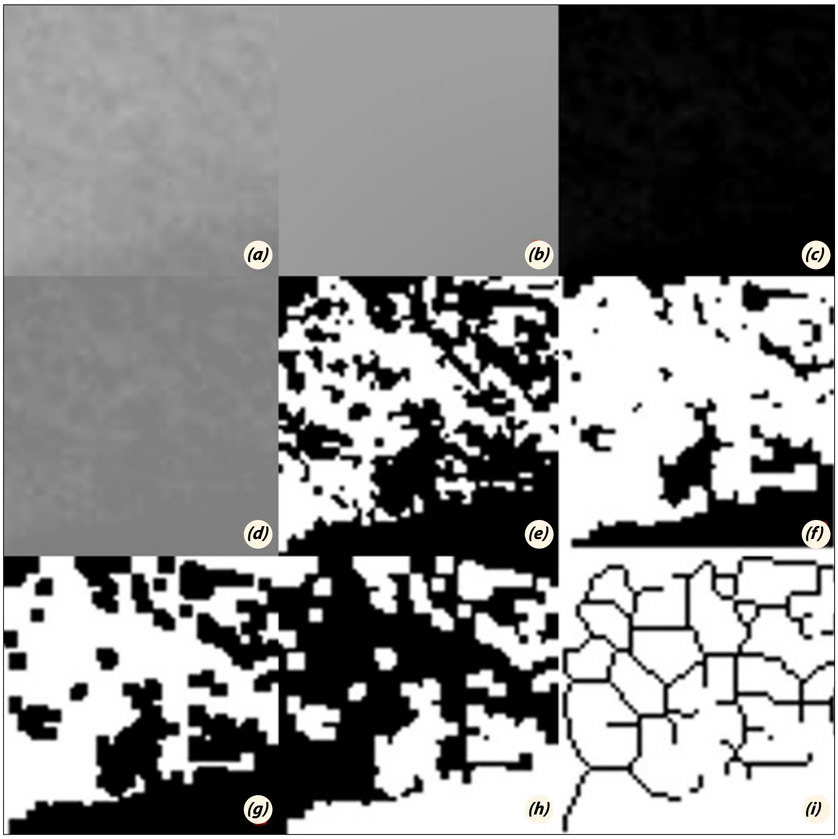

Fig. 3. Fractal analysis steps (a-i). **a)** Cropped and dublicated ROI **b)** Blurring of the duplicated image by applying the Gaussian blur filter **c)** Subtraction of the blurred image from the original image **d)** Addition of 128 gray values to each pixel location. **e)** Threshold. **f)** Erosion. **g)** Dilatation. **h)** Applied inversion processes to the image. **i)** Skeletonization.

generating a blurred version, we subtracted it from the original (Fig. 3c). A constant gray level of 128 was added to highlight marrow spaces and trabecular bone (Fig. 3d). The image was converted to black–white using a brightness threshold of 128 (Fig. 3e), and then processed with erosion, dilation, and inversion (Fig. 3f–h). As a final step, the image underwent skeletonization (Fig. 3i).

The tooth was considered to have successful healing if it was still present in the mouth, no disruption in the marginal adaptation of the tooth's coronal restoration was observed radiographically, and the FA results showed an increase in fractal dimension (FD) values in the periapical region. No change in FD values was considered uncertain, whereas a decrease in FD values was considered unsuccessful healing or no healing. Teeth classified as uncertain were scheduled for reevaluation after completing the 4-year follow-up period recommended by the ESE.

In the present dataset, no cases fell within the predefined "uncertain" range, which was defined as a change in FD values within ±0.01. All analyzed cases showed either an increase or a decrease exceeding this threshold. This may be attributed to the relatively long follow-up period (mean 24.3 months), which allowed sufficient time for bone remodeling processes to manifest as detectable changes in FD. Therefore, all included teeth could be objectively classified as healed or not healed based on the FD trend.

Statistical Analysis

Statistical analysis was performed using SPSS 26 software (IBM Corp., Armonk, NY, USA). The Kolmogorov–Smirnov test indicated that the quantitative FA data did not follow a normal distribution. The Wilcoxon test was used to compare the FD values before the initial RCT and retreatment with those obtained 2 years after the procedures. Spearman's correlation coefficient was used to analyze the changes in FD values before and after the procedures. The Chi-square test was used to compare the proportions of patients with and without healing between the two groups and between the genders and between the age groups (18–35, 36–50, and 51–65 years). The significance level was determined as 0.05.

Results

In this retrospective study, FA was used to calculate the changes in FD values from panoramic radiographs taken before treatment and 2 years after treatment. The radiographs of a total of 56 male and 80 female patients, including 71 initial RCTs and 65 retreatments, were evaluated.

No statistically significant difference was found between the healing rates of the initial RCT and retreatment procedures ($p>0.05$). The healing rate was 85.9% for the initial RCT, whereas it was 81.5% for retreatment procedure (Table 1).

The healing rates after the initial RCT and retreatment did not significantly differ between the genders ($p>0.05$). The healing rate following the initial RCT was 89.7% in females and 83.3% in males. For retreatment, the healing rate was 84.3% in females and 71.4% in males. When patients were categorized into three age groups (18–35, 36–50, and 51–65 years), healing and non-healing outcomes were analyzed within each group based on treatment type. Although slight differences in healing rates were observed across the groups, no statistically significant association was found between age group or treatment procedure and healing outcomes ($p>0.05$) (Table 1).

There was a statistically significant difference between the FD values measured before treatment and 2 years after treatment in patients who underwent initial RCT and retreatment procedures ($p<0.05$) (Table 2).

Discussion

In teeth with CAP, a successful RCT is expected to eliminate microorganisms and necrotic tissues, halt periradicular tissue destruction, and observe new bone formation in

Table 1. Distribution of healed and unhealed outcomes by treatment procedure, gender and age groups

	Healed (n=114)	Unhealed (n=22)	Total (n=136)	*p* Value*
Treatment Procedure				
Initial Root Canal Treatment	61 (85.9)	10 (14.1)	71 (52.2)	0.646
Retreatment	53 (81.5)	12 (18.5)	65 (100)	
Gender				
Female	69 (60.5)	11 (50)	80 (58.8)	0.495
Male	45 (39.5)	11 (50)	56 (41.2)	
	Initial Root Canal Treatment		**Retreatment**	
	Healed (n=61)	Unhealed (n=10)	Healed (n=53)	Unhealed (n=12)
Gender				
Female	26 (89.7)	3 (10.3)	43 (84.3)	8 (15.7)
Male	35 (83.3)	7 (16.7)	10 (71.4)	4 (28.6)
p Value*	0.511	0.271		
Age Group (years)				
18-35	21 (87.5)	3 (12.5)	18 (85.7)	3 (14.3)
36-50	22 (88)	3 (12)	20 (83.3)	4 (16.7)
51-65	18 (81.8)	4 (18.2)	15 (75)	5 (25)
p Value*	0.801	0.650		

The data are presented as the number of frequencies (%). *χ^2 Test.

Table 2. Comparison of changes in fractal dimension (FD) values between baseline and 2-year follow-up radiographs for the initial root canal treatment and retreatment groups

	FD Value			
	Baseline median(min-max)	2-year follow-up median(min-max)	r	*p* Value*
Initial Root Canal Treatment	1.2 (1 – 1.4)	1.3 (1.1 – 1.7)	0.238	<0.01
Retreatment	1.2 (0.9 – 1.5)	1.3 (1.1 – 2.3)	0.431	<0.01

*Wilcoxon Test, r: Correlation Coefficient.

follow-up radiographs (24,25). The European Society of Endodontology (ESE) (2006) recommends at least 4-year of clinical and radiographic follow-up to confirm the complete healing of AP (12). According to ESE's most recent clinical practice guidelines, when RCT is evaluated at least 1 year postoperative, the absence of symptoms such as pain, tenderness, or swelling; the absence of a sinus tract or functional loss; and radiographic reduction in the size of the periapical lesion indicate a positive healing outcome (26). However, Huumonen and Ørstavik reported that the healing of preexisting periapical lesions can be radiographically evident within 3 months to 2 years (27). The present study aimed to compare the changes in the size of periapical lesions in teeth between the initial RCT and retreatment procedures using FA on panoramic radiographs after 2 years of follow-up.

Previous studies examining the factors affecting the success of initial RCT and retreatment procedures have employed various clinical and radiographic evaluation methods (28). PAI is a subjective method used to assess periapical health radiographically and is frequently utilized in the endodontic literature (29). Another radiological examination method used for the quantitative evaluation of changes in periapical trabecular bone is FA (14). FA is a technique that allows for the quantitative assessment of changes in trabecular bone structure on based pixel density in a radiographic image (30). It is a simple, cost-effective, noninvasive, objective, and quantitative analysis method (16,31). One of its advantages is that it is not affected by minor changes in the projection angle or radiodensity (13,32). Additionally, this analysis can detect even very early changes in bone trabeculae within a small area (14). Higher FD values indicate less void space within the bone and increased complexity in bone trabeculation, whereas lower FD values suggest more void space within the bone and less bone trabeculation (33).

FA is used to evaluate bone changes associated with periodontal disease (34), alveolar bone surgery (35), systemic diseases (36), and early changes in the periapical bone following RCT (14). In previous studies by Tosun et al. (37), changes in the mean FD values of periapical lesion areas on 1-year follow-up radiographs after retreatment were similar to changes in the PAI scores (22). Similarly, in a study by Yilmaz et al. (38), which compared the healing of apical lesion after retreatment, FD values in the relevant areas significantly increased in the 1-year follow-up radiographs, and this result was consistent with changes in the PAI scores.

FA is not affected by minor changes in radiographic settings such as kVp, mA, or X-ray angulation (39,40). However, some studies have reported that FA results can be influenced by the location, size, and shape of the ROI (41,42). Another study reported no such effect (43). To ensure consistency in this study, preoperative and postoperative radiographs taken with a panoramic radiograph device using the same exposure settings were utilized. Additionally, the ROI was selected by a single observer in a manner that excluded surrounding anatomical structures such as tooth roots, lamina dura, and the mandibular canal, and it was placed in the same size and position on both preoperative and follow-up radiographs. This ensured that only changes in the area of the lesion were evaluated.

Periapical radiography, panoramic radiography, and cone-beam computed tomography (CBCT) are radiographic methods used for monitoring periapical lesions in endodontics. CBCT provides three-dimensional imaging of the periapical lesion area (44). However, due to its higher cost and exposure to ionizing radiation than two-dimensional radiographs do, its routine use in monitoring periapical lesions is limited. Instead, periapical radiography is used for lesion monitoring, as it allows for a more detailed evaluation of the affected area while utilizing less ionizing radiation than panoramic radiography does (30). However, due to the retrospective nature of the present study, routine panoramic radiographs taken from patients who returned to the dental faculty hospital 2 years later for endodontic or other reasons were used.

In clinical studies, numerous factors can influence the outcome of RCT (45). The preoperative conditions of the teeth (pulp and periapical status, size of the periapical lesion, history of trauma, resorption, fracture, cracks, swelling, and presence of a sinus tract) can potentially affect the treatment outcome. In the literature, many studies have demonstrated that the preoperative condition of the periapical lesion is a significant factor influencing the prognosis of RCT (46,47). In studies conducted by Friedman et al. (4) and Farzaneh et al. (48), the rate of periapical healing 4–6 years after initial RCT was significantly better in teeth without preoperative CAP than in those with CAP. Additionally, in retreatment cases, the success rate was significantly lower in the presence of a periapical lesion than in cases without lesions (49,50). Farzaneh et al. (51) compared the periapical healing rate of root canal-treated teeth without AP to those with AP 4–6 years after retreatment. The healing rate after retreatment was 97% in teeth without AP, whereas this rate decreased to 78% in teeth with AP. These studies in the literature confirm the negative impact of preoperative AP on periapical healing.

Primary treatment and nonsurgical retreatment differ markedly in prognosis. In retreatment cases, outcomes are affected by tooth type, presence/size of any preoperative radiolucency, presenting symptoms, periodontal status, the integrity of the coronal restoration and prior endodontic work, and whether an intracanal post is present (52). Because retreatment follows failure of the initial RCT, its prognosis may be diminished by a microflora that is harder to eradicate (49), often dominated by gram-positive monoinfections, most notably Enterococcus faecalis (49,53). Consistent with these challenges, healing rates are generally higher after primary RCT than after retreatment, as reported by Sjögren et al. (46) and Friedman et al. (54).

In the present study, we aimed to evaluate how FA, as a quantitative method, can be used to assess the outcomes of the healing of apical lesion areas following RCT and retreatment of teeth. This study is the first to use FA as the sole method to comparatively evaluate the outcomes of initial RCT and retreatment procedures. Our results demonstrated that FD values significantly increased in both treatment groups 2 years after treatment compared with the preoperative values. This increase in FD values indicates new bone formation in the apical region along with an increase in trabeculation. These findings are consistent with those of previous studies (22,37,38,55). The results of the study revealed no statistically significant difference in periapical healing, as determined by changes in FD values, between initial RCT and retreatment groups ($p>0.05$), thereby supporting the acceptance of the null hypothesis (H_0).

Although gender-based biological differences, including hormonal influences on bone metabolism, may theoretically affect healing dynamics, the current evidence suggests that gender alone is not a significant determinant of periapical healing. Previous studies have similarly reported no statistically significant gender-related differences in healing outcomes when using either clinical or fractal analysis parameters (46,55,56). Similarly, in the present study, no significant difference was found between genders in terms of healing rates following initial RCT and retreatment procedures. Therefore, our findings are consistent with existing literature, supporting the notion that treatment-related and lesion-specific factors are likely to play a more decisive role than sex-based biological variation.

In addition to the overall analysis, patients were stratified into three clinically relevant age groups (18–35, 36–50, and 51–65 years) to evaluate the potential influence of age on periapical healing. Healing rates across these subgroups were slightly different numerically but did not demonstrate statistically significant differences between age groups or treatment modalities. These findings suggest that, within a healthy population aged 18 to 65 years, age alone may not be a determining factor in periapical healing outcomes following either initial treatment or retreatment. Nonetheless, the biological variability associated with age—such as changes in bone metabolism or hormonal status —may not be fully captured in this retrospective design. Therefore, future prospective studies with stratified and adequately powered samples are needed to further explore age-related differences in healing dynamics.

The present study has several limitations. First, due to its retrospective design, the evaluation of treatment success was based solely on radiographic parameters, without the inclusion of clinical signs and symptoms such as pain, swelling, or sinus tract presence. Additionally, functional status and standardized indices like the PAI, which are commonly used in conjunction with radiographic evaluations, were not assessed owing to the lack of uniform clinical documentation. Instead, periapical healing was determined solely through changes in FD values obtained from panoramic radiographs. Although FA offers a quantitative and objective measure, relying exclusively on this method may not fully capture the complexity of biological healing. Furthermore, although PAI scoring was excluded due to projection variability and anatomical superimposition on panoramic images, the same radiographs were used for FA. However, unlike PAI, fractal analysis has been shown to be less sensitive to variations in angulation and projection geometry, particularly when the ROI is standardized in size and location (13,39). In the present study, all radiographs were obtained using the same panoramic unit under consistent exposure parameters, and ROI placement was performed by a calibrated observer. Moreover, the use of panoramic radiographs—despite their practicality and standardization—comes with inherent limitations in spatial resolution compared to periapical imaging. Specifically, only gross defects in coronal restorations that were clearly visible on panoramic radiographs—such as pronounced marginal gaps, overhangs, or recurrent caries—were used as exclusion criteria. However, panoramic imaging may not reliably detect minor marginal discrepancies, which can still compromise the integrity of the coronal seal and negatively influence periapical healing. Additionally, the relatively short follow-up period (approximately 24 months), although sufficient for initial bone remodeling, does not meet the 4-year follow-up interval recommended by the ESE for definitive confirmation of healing.

Conclusion

FA, which is based on objective and quantitative criteria, is a reliable method for monitoring the healing of periapical lesions following initial RCT and retreatment. According to the FA results, the healing rate in the periapical region was similar between the two treatment procedures.

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ORIGINAL ARTICLE

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Fracture resistance of endodontically treated teeth restored with composite and CAD/CAM resin using different NaOCl concentrations

Ceren Gizem Karatekin,[1] Gaye Sağlam,[2] Murat Koçak,[3] Sibel Koçak,[3] Baran Can Sağlam[3]

[1]Denizli Oral and Dental Health Hospital, Denizli, Türkiye
[2]Department of Proshodontics, Zonguldak Bülent Ecevit University Faculty of Dentistry, Zonguldak, Türkiye
[3]Department of Endodontics, Zonguldak Bülent Ecevit University Faculty of Dentistry, Zonguldak, Türkiye

Purpose: The aim of this study was to evaluate the fracture resistance of endodontically treated teeth restored by direct and indirect techniques using different concentrations of NaOCl.

Methods: Seventy extracted maxillary premolars were used. Ten teeth were not treated (control group). The remaining 60 teeth were divided into two main groups, according to the type of restoration applied: composite and computer-aided design/computer-aided manufacturing (CAD/CAM) (N=30). Standard MOD cavities and access cavities were prepared, according to the groups. Teeth in each main group were divided into three subgroups according to the irrigation used (distilled water, 2.5% sodium hypochlorite (NaOCl) and 5.25% NaOCl) (n=10). During root canal preparation, each subgroup of composite and CAD/CAM was irrigated with distilled water, NaOCl with 2.5% NaOCl concentration and NaOCl with 5.25% NaOCl concentration. After root canal filling, the specimens were restored with nanohybrid composite resin and CAD/CAM technique using nanohybrid composite block. All teeth were subjected to fracture testing using a universal testing machine.

Results: No significant difference was obtained in terms of fracture strength when irrigation solutions were compared in both composite groups and CAD/CAM groups ($p>0.05$). The fracture strength of the teeth restored with composite resin was statistically significantly higher than the teeth restored with CAD/CAM in each distilled water, 2.5% NaOCl, 5.25% NaOCl solutions ($p<0.05$).

Conclusion: NaOCl irrigation solution used in root canals did not affect the fracture strength of the teeth. The fracture strength of direct composite restorations used in coronal restorations was higher than that of CAD/CAM restorations.

Keywords: CAD/CAM; composite resin; fracture resistance; NaOCl.

Introduction

Effective root canal treatment requires the thorough cleaning of the infe1cted root canal system, removal of necrotic pulp, and obturation of root canal (1). During mechanical root canal preparation, irrigation solutions are used to remove infected dentin chips, eliminate bacteria,

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Correspondence: Baran Can Sağlam. Bülent Ecevit University Faculty of Dentistry, Department of Endodontics, Kozlu, Zonguldak, Türkiye

Tel: +90 505 – 874 35 27 e-mail: barancansaglam@gmail.com

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and lubricate the canal (2,3). NaOCl is widely used as an irrigation solution in clinical practice due to its ability to dissolve infected tissue. However, hypochlorite solutions can affect the mechanical properties of dentin by degrading organic components. The recommended concentration of NaOCl is between 0.5% and 5.25%, although there is no consensus on the ideal concentration. Although a high concentration of NaOCl can enhance the dissolution of organic tissue, it can also negatively affect dentin (4).

Coronal restoration is crucial for the success of endodontically treated teeth. Incomplete or false coronal restoration after successful root canal treatment has been shown to adversely affect tooth survival (5). Therefore, the choice of materials for restoring endodontically treated teeth is of great importance in increasing their resistance to fracture.

Composite resin material is widely used in dental practice because of its acceptable aesthetic properties, sufficient adhesion to enamel and dentin, and support of the remaining tooth structure (6). Despite the high compressive strength and fracture resistance of composite resin, polymerisation shrinkage causes marginal gaps and microleakage, resulting in hyperemia and hypersensitivity (6). Indirect restorative techniques have been developed to reduce the limitations of direct composite restorations in root canal treated teeth.

In recent years, (CAD/CAM) technology has been frequently used in the production of indirect restorations, particularly in the production of aesthetic restorations. The advantages of this technique are many, including the ability to perform the procedure in a single session, the ability to create a restoration which is very similar to the natural tooth, and the ability to reduce the risk of errors in the clinical and dental laboratory process (7).

The objective of this study was to assess the fracture resistance of teeth that have been treated endodontically and restored by direct and indirect techniques using different concentrations of NaOCl. The first null hypothesis of the study is that irrigation with different concentrations of NaOCl solution does not affect the fracture resistance. The second null hypothesis is that different restoration techniques do not affect the fracture resistance of teeth.

Materials and Methods

This study was supported by Zonguldak Bülent Ecevit University Scientific Research Projects (Project No: 2020-13442734-01) and conducted according to Helsinki Declaration. The ethical principles of this in vitro study were approved by the Zonguldak Bülent Ecevit University Ethics Committee with the report numbered 2020/13 (Date: 24/06/2020).

Sample preparation

Seventy maxillary premolar teeth that were extracted due to periodontal problems were used in the present study. Soft and hard tissue residues around the extracted teeth were removed using an ultrasonic device. Teeth with fractures, cracks, open apex, perforation, root canal treatment, or resorption were excluded from the study.

Endodontic procedure

The teeth were divided into two main groups according to the type of restoration applied (n=30). The teeth in each main group were divided into three subgroups according to the irrigation used (distilled water, 2.5% NaOCl and 5.25% NaOCl) (n=10). After working length determination, root canals were instrumented using the ProTaper Next (Dentsply Maillefer, Ballaigues, Switzerland) file system, with an apical diameter of # 25.06 up to the X2 file. The control and experimental groups of the study are shown in Table 1. Group 1 was accepted as the control group and no cavity preparation or endodontic procedure was performed.

In Group 2 and Group 5, 2.5 ml of distilled water solution was used after each file use. In Group 3 and Group 6, 2.5 ml of 2.5% NaOCl solution was used after each file use. Finally, for the last irrigation, 5 ml of 2.5% NaOCl solution was used in the root canals. In Group 4 and Group 7, a total of 2.5 ml of 5.25% NaOCl solution was used in each canal after each file use. The final rinse used 5 ml of 5.25% NaOCl solution in the root canals. In all test groups, 10 ml of distilled water was applied for 5 minutes to remove the solution and residues from the root canal.

Root canals were obturated with a sealer (AH Plus, Dentsply, Konstanz, Germany) and gutta percha using single-cone technique. Flowable composite resin (Estelite Universal Flow, Tokuyama Dental Corp, Tokyo, Japan) was used to cover the root canal filling. The teeth were stored in humidity (100%) for 48 hour.

Cavity preparation

Following root canal filling, standardized MOD cavity preparations were created using 2 mm diameter round and fissure burs (Diatech Swiss Dental Instruments, Altstätten, Switzerland). The buccal and palatal walls were 2.5 mm ± 0.2 mm thick, and the cavity floor was positioned 1.5 mm above the enamel-cementum junction. To mimic the periodontal ligament, a thin layer of light body impression material (Oran-wash L, Zhermack, Italy) was applied to the roots. The roots were then embedded in acrylic resin blocks in a silicone mold up to 1.5 mm below the enamel-cementum junction.

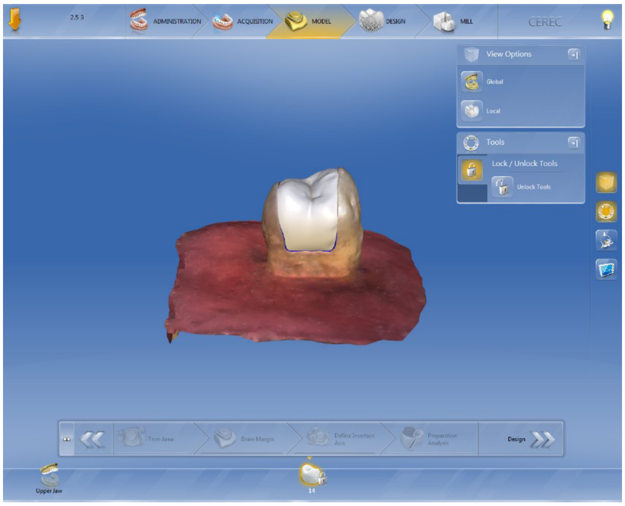

Fig. 1. Restoration design.

Restoration Composite Resin Groups

In group 2, 3 and 4 MOD cavity preparations were restored with nano-hybrid composite (Palfique Estelite, Tokuyama Dental Corp, Tokyo, Japan) by using direct technique. First, enamel tissue etching was performed with phosphoric acid gel (37%, i-Gel, i-Dental, Lithuania) for 30 seconds and washed for 15 seconds. The enamel surfaces of teeth with MOD cavities prepared using the selective etching technique were conditioned with 37% phosphoric acid gel (i-Gel, i-Dental, Lithuania) for 30 seconds. Subsequently, the surfaces were rinsed with water for 15 seconds and gently air-dried. Following the etching procedure, the bonding agents Bond A and Bond B (Tokuyama Universal, Tokuyama Dental, Tokyo, Japan) were mixed in a designated mixing well according to the manufacturer's instructions. The mixed adhesive was applied to the cavity surfaces using an applicator for 20 seconds and gently dispersed with an air syringe for 5 seconds to ensure uniform distribution over the cavity walls. Nano hybrid composite resin was placed in the cavity in 2 mm layers and polymerized with light cure (curing time for each layer: 20 seconds; light intensity: 1200 mW/cm2; Woodpecker, Guilin, China). Restorations were completed with finishing and polishing processes.

Restoration of CAD/CAM Groups

The restoration of the teeth belonging to groups 5, 6 and 7 was performed indirectly with CAD/CAM using nano hybrid block (Voco, Grandio Block, Italy). After opening the software on the computer and identifying the credentials, the "Application" tab was started. In the Indication tab, "Restoration Type" was selected as "Crown" and "Design Type" was selected as "Biogeneric Individual". GC Cerasmart was selected in the "Material" section. In order to standardize the occlusal form and anatomy of the specimens, the upper first premolar from the CEREC database was selected to determine the occlusal surface characteristics of all specimens.

The teeth were measured with an optical impression camera (Cerec Omnicam, Dentsply Sirona, USA). The model tab was switched to and the image was positioned on the maxillary arch. After determining the margin drawing and the entryway, the restoration was designed in the "Design" tab. The design of the restoration was prepared and created in three dimensions in digital environment with CEREC 4.4.1 software (Fig. 1).

After the design of the restoration, the production phase began. Crown restorations were fabricated with nano hybrid composite block (Voco, Grandio Block, Italy) in the milling unit (CEREC MC XL, Sirona, USA). The obtained crowns were removed from the milling unit, the crowns were corrected with a fine-grained diamond bur and the completed restorations were adapted to the teeth.

Cementation was performed using a self-etch adhesive cement (Han, Brussels, Belgium). Residual cement was removed with a probe and polymerization of the cement was achieved with an LED light device (Woodpecker, Guilin, China). The restorations were polished with polishing rubbers (Kenda Polishers).

Fracture Strength Test

The fracture strength of the teeth in the control group, composite and CAD/CAM groups, was measured using an universal test machine (Instron, Canton, MA, USA). A 2 mm diameter metal probe with a rounded tip was inserted into the tester to apply force to the teeth. Specimens embedded in the acryl block were placed on the adjustable metal part. The rounded metal rod was placed in the central groove of the premolars, parallel to the long axis of the tooth, and force was applied to the specimens. The application rate of the load was set to 1 mm/min. The fracture values of the tooth and restoration were recorded in Newton (N) (Fig. 2).

Fracture types

In order to determine the fracture types, the fractured specimens were examined under X25 magnification in a dental operating microscope (Leica DM4000B, Germany). The fracture types were classified as follows (8);

Type I: No fracture

Type II: Fracture limited to the tooth

Type III: Fracture limited to restorative material

Type IV: Fracture observed in the restorative material above the enamel-cement border

Fig. 2. Fracture strength set-up

Type V: Fracture observed in the restorative material is below the enamel cement border

Type II, III and IV fractures were considered as repairable fractures. Type V fractures were considered as non-repairable fractures.

Statistical Analysis

The data were analysed using IBM SPSS V23 software. The normal distribution of the data was assessed using the Shapiro-Wilk test. One-way analysis of variance (ANOVA) was used for normal distribution comparisons and Tukey HSD test was used for multiple comparisons. Chi-square test was used to compare fracture types and repairability according to the groups. The level of significance was $p<0.05$.

Fig. 3. Representative image of the fracture type.

Results

The statistical values for the fracture strength test of all groups are shown in Table 1. Group 1 (Control) showed statistically significantly higher values than all other tested groups ($p<0.05$). When the groups were compared in respect to the irrigation solution used, there was no significant difference between Groups 2, 3 and 4 with composite restoration ($p>0.05$). When the CAD/CAM groups compared in terms of the irrigation solution used; there was no significant difference between Groups 5, 6 and 7 ($p>0.05$).

When both types of restorations were compared in terms of distilled water, 2.5% NaOCl and 5.25% NaOCl irrigation solutions, the composite restoration groups (Groups 2, 3 and 4) showed higher fracture strength values than the CAD/CAM restored groups (Groups 5, 6 and 7) in all solutions ($p<0.05$).

All specimens in the study were found to be fractured. Type II fractures were observed in all specimens in the control group (Fig. 3). In the composite groups (groups 2, 3 and 4), high rates of type IV and V fractures were observed. Evaluation of the CAD/CAM restored groups showed that type II and IV fractures were common in group 5, 40% type II fractures and 30% type IV fractures in group 6. In group 7, type V fractures occurred in 50%, type II fractures in 30% and type IV fractures in 20% (Table 2).

In the composite groups, 60%, 70% and 40% of the fractures were non-repairable in Groups 2, 3 and 4, respec-

Table 1. Fracture resistance values of all groups. (Different superscript letters determines significant difference.)

	N	Mean	St. dev	Median	Minimum	Maximum
Group 1 (control)	10	1806.5562[a]	373.6483	1837.0398	927.61	2286.52
Group 2 (Distilled water Composite)	10	1046.2668[b]	284.66560	994.9159	612.42	1606.54
Group 3 (2.5% NaOCl Composite)	10	1092.3855[b]	216.32544	1083.1568	727.02	1499.21
Group 4 (5.25% NaOCl Composite)	10	1046.2668[b]	284.66560	994.9159	612.42	1606.54
Group 5 (Distilled water CAD/CAM)	10	643.6253[c]	127.49495	687.4905	404.74	831.19
Group 6 (2.5% NaOCl CAD/CAM)	10	645.3140[c]	128.80215	667.5145	452.97	802.88
Group 7 (5.25% NaOCl CAD/CAM)	10	615.8555[c]	147.17863	609.6923	381.58	870.32

CAD/CAM: Computer-aided design/computer-aided manufacturing.

Table 2. Fracture type percentages

	Type II	Type III	Type IV	Type V
Group 1 (control)	10 (100%)	0	0	0
Group 2 (Distilled water Composite)	0	1(10%)	3(30%)	6(60%)
Group 3 (2.5% NaOCl Composite)	0	0	3(%30)	7(%70)
Group 4 (5.25% NaOCl Composite)	0	1(10%)	5(50%)	4(40%)
Group 5 (Distilled water CAD/CAM)	4(40%)	0	4(40%)	2(20%)
Group 6 (%2.5 NaOCl CAD/CAM)	4(40%)	1(10%)	3(30%)	2(20%)
Group 7 (%5.25 NaOCl CAD/CAM)	3(30%)	0	2(20%)	5(50%)

CAD/CAM: Computer-aided design/computer-aided manufacturing.

tively. In CAD/CAM fractures, 80% of repairable fractures occurred in Groups 5 and 6.

Discussion

Irrigation solutions used during root canal treatment may cause structural changes in the inorganic and organic parts of dentin. These changes in the structure of dentin may cause a change in the physical properties of dentin and make the tooth more brittle (9).

Extensive significant loss of tooth structure in the teeth after root canal treatment affects the resistance of the teeth against intraoral forces (10). In addition, with the decrease in the amount of collagen in the dentin, a loss of approximately 14% in the resistance of the tooth was observed (11). The high loss of hard tissue causes vertical root fractures, crown and cusp fractures in root canal treated teeth. Magne et al. (12) reported that stress intensity increased in teeth with endodontic access cavities in which the marginal ridge was removed. It was also observed that fracture resistance decreased by 63% in teeth with MOD cavity preparation (13).

Alveolar bone support and periodontal ligament are important for stress distribution on teeth. In previous studies, elastomeric impression material has been used to mimic the way the load of occlusal forces is distributed to the alveolar bone (14,15). It has been reported that periodontal ligament simulation and embedding method may affect the fracture load and fracture type in fracture strength tests (15). In the present study, silicone impression material was used to simulate the periodontal ligament.

Composite resin is commonly used in dental practice due to its ease of use, good adaptation to the cavity wall, and satisfactory aesthetic properties. The development of resin composites and adhesive systems has enabled the creation of aesthetic restorations for both anterior and posterior teeth. To address the limitations of composite resin restorations, the use of indirect restorations prepared and cemented outside the mouth is recommended (16). The anatomical shape of the teeth and the formation of proximal contacts are facilitated, while the polymerisation shrinkage is limited to thin resin cement (17).

The elastic modulus of composite block materials is close to that of natural teeth. Therefore, composite blocks have higher fracture strength compared to glass ceramic blocks (17). Based on this reason, CAD/CAM nano-hybrid composite blocks were used the present study rather than glass ceramic materials.

According to the results obtained in the present study, there was no significant difference between distilled water, 2.5% NaOCl and 5.25% NaOCl in both composite and CAD/CAM groups. Therefore, the first hypothesis of this study was accepted. Some studies in the literature reported that NaOCl irrigation did not significantly affect the fracture resistance of the teeth in accordance with the results of the present study. Feiz et al. (18) applied different irrigation solutions to the post cavity after root canal treatment and examined the effect of irrigation solutions on the fracture resistance of the teeth and showed no significant effect on the fracture resistance of the tooth. In another study, Küçük et al. (19) reported that NaOCl solution at 1% and 5.25% concentration had no effect on the fracture resistance of root canal treated teeth.

When the results of previous studies were analysed, it was found that dentin dehydration and disorders in collagen structure affect the biomechanical properties of dentin (20). In addition, NaOCl has also been reported to affect the fracture strength of dentin (21,22). However, it is known that the most important factor in the fracture strength of the tooth is the amount of intact tooth structure remaining in the tooth to be restored. The size and the taper of final root canal instrument was selected as 25/.06 in all samples for standardization similar to previous fractture strength study (23).

In the present study, composite groups showed higher fracture resistance than CAD/CAM groups regardless of the irrigation solutions used. Accordingly, the second hypothesis of this study was rejected. In reviewing the literature, there are previous studies that are compatible with the present study in terms of the type of material used. Bajunaid et al. (24) noted that the fracture resistance of the direct composite resin groups was higher than that of the indirect and ceramic CAD/CAM groups in premolar teeth in which direct composite resin, indirect composite resin and ceramic CAD/CAM were used in OM cavity preparation. Liu et al. (25) restored teeth with MOD inlay cavity design using composite resin and CAD/CAM. They found that the fracture resistance of the composite resin group was higher.

The lower fracture strengths in the groups with CAD/CAM composite blocks may be related to the cavity design and the presence of resin cement rather than the material. Previous studies indicated that tubercle-protected restorations should be used in cases of excessive material loss and wall thicknesses of 2 mm or less (8,26). The fracture strength may be affected by the ability of pre-polymerised composite resins to transmit forces directly to the cavity walls and the bonding ability of the cement in between. This conclusion is also supported by fracture types. In the CAD/CAM restored groups, a high incidence of wall fractures was observed, rather than material fractures.

In composite restoration groups type IV and V fracture types were recorded higher compared to CAD/CAM groups. This finding also supported the results of a previous report by Kassis et al. (8). The higher rate of unrepairable fractures in the composite groups with high fracture strength compared to the CAD/CAM groups may be due to the better adhesion of the direct composite restoration application with dentin and the failure of the resin cement used in the CAD/CAM group. Further studies are needed to support the results of the study in terms of both composite-containing CAD/CAM materials and cement types used for the restoration of root canal treated teeth with extensive tissue loss.

Conclusion

The following results were found in the study; the concentration of NaOCl solution does not affect the fracture strength in teeth restored with both direct composite and CAD/CAM blocks. Regardless of the irrigation solution used, direct composite restoration showed higher fracture strength than teeth restored with CAD/CAM. Further studies are needed on different restorative materials, CAD/CAM blocks and cements that can be used in the restoration of root canal treated teeth

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ORIGINAL ARTICLE

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Effects of bleaching agents on the surface microhardness and surface morphology of calcium silicate-based cements: An in vitro study

Pınar Naiboğlu,[1] Tuğba Koşar,[2] Ali Çağın Yücel[3]

[1]Department of Restorative Dentistry, Giresun University Faculty of Dentistry, Giresun, Türkiye
[2]Department of Endodontics, Karadeniz Technical University Faculty of Dentistry, Trabzon, Türkiye
[3]Department of Endodontics, Giresun University Faculty of Dentistry, Giresun, Türkiye

Purpose: To assess the effects of exposure to sodium perborate, carbamide peroxide, and hydrogen peroxide on the surface microhardness and surface morphology of ProRoot MTA and Biodentine.

Methods: A total of 50 specimens of each cement, ProRoot MTA and Biodentine, were prepared. The specimens were assigned into 5 groups based on the bleaching agent applied (n=10): A mixture of sodium perborate and distilled water (SP-DW), a mixture of sodium perborate and 3% hydrogen peroxide (SP-HP), carbamide peroxide (CP), hydrogen peroxide (HP), and control group. Bleaching agents were changed four times on every fourth day. Surface microhardness and surface morphology were assessed using a microhardness tester and scanning electron microscope, respectively. Data were analysed using two-way ANOVA and Tukey's test.

Results: All bleaching agents caused morphological differences on the surfaces of the both cements. All bleaching agents, except SP-DW, caused a decrease in the microhardness of both cements, with HP causing the greatest decrease, followed by CP and SP-HP, respectively. Biodentine showed higher surface microhardness values than ProRoot MTA in all groups.

Conclusion: Biodentine may be recommended as a cervical barrier and a mixture of sodium perborate and distilled water may be the safest bleaching agent to preserve the surface properties of CSCs.

Keywords: Bleaching agents; calcium silicate-based cements; microhardness; surface morphology.

Introduction

Tooth color plays a crucial role in creating an esthetically pleasing smile, significantly affects esthetic self-perception, and has a psycho-social effect on individuals (1–3). When a single tooth becomes discolored, its negative impact on appearance can be particularly noticeable, as it disrupts the overall harmony of the smile (4). Intracoronal bleaching offers a conservative approach to improving the esthetics of discolored root-filled teeth (5). In most cases, multiple appointments are needed to achieve the desired shade and match the color of the darkened tooth to the surrounding teeth (6).

Intracoronal bleaching can be performed using different

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Correspondence: Pınar Naiboğlu. Department of Restorative Dentistry, Faculty of Dentistry, Giresun University, Giresun, Türkiye
Tel: +90 454 – 310 27 06 e-mail: pinar.naiboglu@hotmail.com

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bleaching agents, including hydrogen peroxide, carbamide peroxide, a mixture of sodium perborate and hydrogen peroxide or distilled water (6,7). Bleaching is usually achieved by the release of hydrogen peroxide from these agents followed by diffusion of reactive oxygen species along the dentinal tubules, oxidizing pigments and restoring tooth color (5). Due to their acidity, bleaching agents may etch the dentin surface, disturb the smear layer covering the dentinal tubules, and lead to greater permeability. As a result, greater amounts of hydrogen peroxide can penetrate the dentinal tubules and external cervical resorption may occur if the level exceeds the critical limit (7). To reduce this risk, it is recommended to place a cervical barrier prior to intracoronal bleaching (6,7).

Mineral trioxide aggregate (MTA), the first introduced calcium silicate-based cement (CSC) (8), can be used in vital pulp treatment, apexification, root-end filling, pulpotomy, repair of perforations, and endodontic surgery (9,10). Despite its beneficial properties such as bioactivity, biocompatibility, antimicrobial efficacy, and sealing ability (11,12), MTA has been criticized for its disadvantages such as difficult handling properties, tooth discolouration, and long setting time (13).

Biodentine™ (Septodont, St. Maur-des-Fossés, France) entered the market in 2009 as a "dentin replacement" with the claim of eliminating some of the disadvantages of MTA. The cement is presented in both powder and liquid components, with the liquid containing $CaCl_2$ to accelerate and regulate the setting process. A water-soluble polymer was added to reduce the quantity of water. This helped in reducing the viscosity of the cement and improving its handling properties (8,14–16). With its superior physical properties such as higher density, compressive strength, surface hardness, flexural strength and elastic modulus, faster setting time, reduced porosity and improved handling properties, Biodentine™ offers a promising alternative to MTA for use in endodontics, restorative dentistry, pediatric dentistry, and dental traumatology (9,17).

In recent years, ProRoot MTA (Dentsply Tulsa Dental, Tulsa, OK, USA) and Biodentine have been investigated for use as a cervical barrier in intracoronal bleaching (18–20). Despite its clinical importance, only a few studies have examined the impact of bleaching agents on the surface microhardness and surface morphology of CSCs (21,22). Therefore, this study focused on evaluating the effects of sodium perborate, carbamide peroxide, and hydrogen peroxide on the surface microhardness and surface morphology of ProRoot MTA and Biodentine using the walking bleach technique. The null hypotheses tested were as follows: (1) bleaching agents would not affect the surface microhardness of both CSCs and (2) bleaching agents would not alter the surface morphology of both CSCs.

Materials and Methods

The manuscript of this laboratory study has been written according to Preferred Reporting Items for Laboratory studies in Endodontology (PRILE) 2021 guidelines (23) (Fig. 1).

Specimen Preparation

A total of 100 cylindric acrylic blocks, each containing a hole 4 mm in depth and 6 mm in diameter were prepared using a self-curing acrylic resin (Imicryl, Konya, Türkiye).

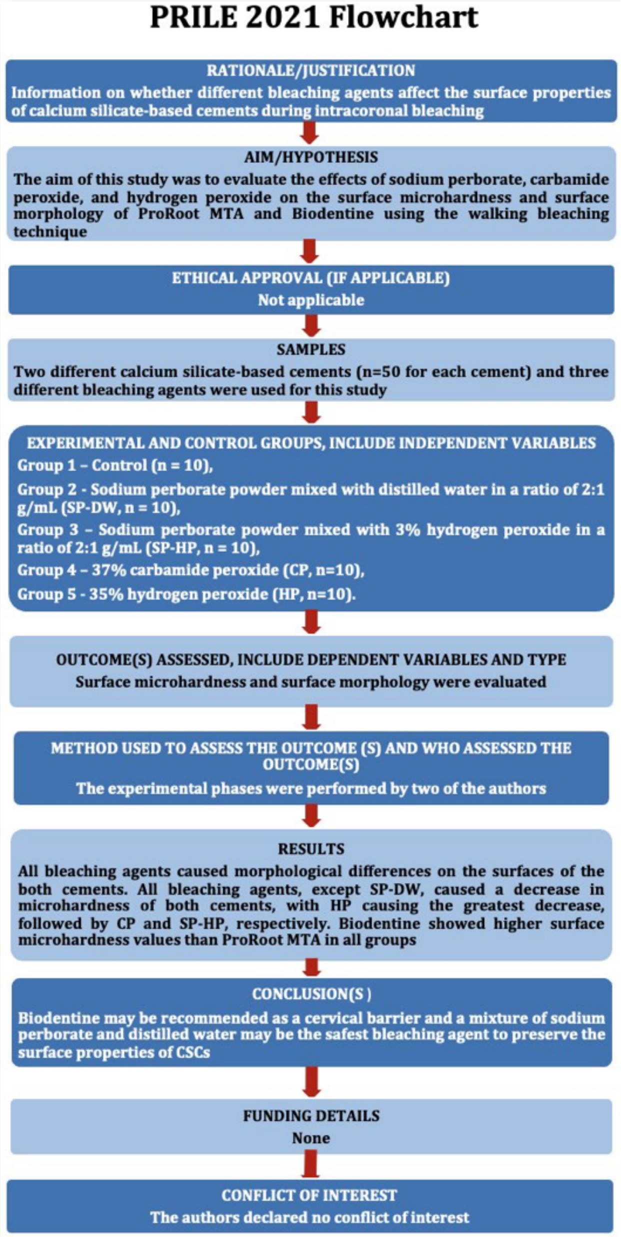

Fig. 1. PRILE 2021 flowchart.

Table 1. Composition, steps of application, manufacturer and lot number details of the CSCs used in the study

CSC	Composition	Steps of application	Manufacturer	Lot number
ProRoot MTA	Powder: Tricalcium silicate, dicalcium silicate, tricalcium aluminate, bismuth oxide, calcium sulphate dehydrate or gypsum Liquid: Water	Mix 1 pouch of powder with 1 micro-dose ampule of liquid for about 1 minute	Dentsply Tulsa Dental, Johnson City, TN, USA	0000304442
Biodentine	Powder: Tricalcium silicate, dicalcium silicate, calcium carbonate and oxide, iron oxide, and zirconium oxide. Liquid: Calcium chloride and hydrosoluble polymer	Pour 5 drops of liquid into the capsule, place the capsule on a mixing device and mix for 30 s	Septodont, Saint-Maur-des-Fossés, France	B28762

CSC: Calcium silicate-based cement.

Table 2. Bleaching agents used in the study

Bleaching agent	Component	Manufacturer
Sodium perborate	Sodium perborate tetrahydrate	Merck KGaA, Darmstadt, Germany
Whiteness Super-Endo	37% carbamide peroxide	FGM Products, Joinville, SC, Brazil
Opalescence Endo	35% hydrogen peroxide	Ultradent Products, Inc., South Jordan, UT, USA

The blocks were allocated into two groups (n=50) according to the type of CSC used: Biodentine (Septodont, Saint-Maur-des-Fosses, France) and ProRoot MTA (Dentsply Tulsa Dental, Johnson City, TN, USA) (Table 1). Each cement, prepared in accordance with the manufacturer's instructions, was placed into the cavities, covered with moist cotton pellets and kept at 37°C with 100% humidity for 96 h. Then, the surfaces of the specimens were polished under constant water irrigation using silicon carbide papers with grit sizes of 600 and 1000 each applied for 30 s. After polishing, the specimens were rinsed using distilled water for 1 min and air-dried for 5s.

50 specimens of each CSC were randomly allocated into 5 groups (n=10) based on the bleaching agent used (Table 2).

Control group: The surfaces of the specimens did not receive any treatment

Sodium perborate-distilled water (SP-DW) group: Sodium perborate powder mixed with distilled water in a ratio of 2:1 g/mL

Sodium perborate-hydrogen peroxide (SP-HP) group: Sodium perborate powder mixed with 3% hydrogen peroxide in a ratio of 2:1 g/mL

Carbamide peroxide (CP) group: 37% Carbamide peroxide

Hydrogen peroxide (HP) group: 35% Hydrogen peroxide

The surfaces of the specimens were treated with bleaching agent, covered with damp cotton pellets and sealed with temporary filling material until the next session four days later (Cavit, 3M ESPE, Seefeld, Germany). The bleaching agent was changed every 4 days and this protocol was repeated four times (6). The temporary material was then removed, the surfaces of CSCs were rinsed using distilled water and dried with air.

Microhardness Measurement

Vickers microhardness measurements were performed on each specimen utilizing a microhardness tester (Duramin Microhardness Tester, Struers, Cleveland, USA) and a diamond indenter applying a 50 g for 10 s. Four indentations were randomly placed on the surface, each at least 1 mm apart from adjacent indentations and the specimen edges. The diagonal diameter of each indentation was evaluated under a microscope and the Vickers microhardness value was recorded. The mean microhardness value was calculated for each specimen.

Scanning Electron Microscope Analysis

For morphological evaluation, 5 additional specimens for each material were prepared as previously described and stored under identical storage conditions. After 96 h, the specimens were allocated into five groups: Control group, SP-DW group, SP-HP group, CP group, and HP group. The relevant bleaching agent was applied to the surfaces of the specimens in the test groups as described earlier.

Table 3. Mean ± standard deviation of surface microhardness (VHN) of each group

	ProRoot MTA Mean ± SD	Biodentine Mean ± SD
Control	45.76±3.97[Aa]	59.42±4.03[Ba]
SP-DW	43.57±2.12[Aab]	56.83±2.34[Ba]
SP-HP	42.34±3.63[Ab]	53.36±3.07[Bb]
CP	35.21±2.64[Ac]	42.35±2.00[Bc]
HP	25.44±2.41[Ad]	35.97±2.61[Bd]

SP-DW: Sodium perborate-distilled water; SP-HP: Sodium perborate-hydrogen peroxide; CP: Carbamide peroxide; HP: Hydrogen peroxide. Different superscript uppercase letters (A,B) in each column and lowercase letters (a,b,c,d) in each row indicate statistically significant differences (p<0.05). SD: standard deviation; VHN: Vickers microhardness.

No treatment was applied to the specimens in the control group. The specimens were sputter-coated with gold using an SPI-Module Sputter Coater (Structure Probe Inc., PA, USA) then examined under a scanning electron microscope (SEM) (EVO LS10, Zeiss, Oberkochen, Germany) to evaluate their surface topography. SEM images of the specimens were obtained at different magnifications (1000x, 2500x, 3000x, and 5000x).

Statistical Analysis

Data were analysed using SPSS 25.0 (SPSS, Chicago, IL, USA) for Windows. Parametric statistical tests were applied after the data were evaluated for normal distribution (Shapiro-Wilk) and homogeneity of variance (Levene test). Two-way analysis of variance (ANOVA) was used to analyse the Vickers microhardness (VHN) data, followed by Tukey's test for post hoc multiple comparisons ($p<0.05$).

Results

Surface Microhardness

Two-way ANOVA indicated that both factors (bleaching agent and CSC) significantly impacted the surface microhardness values ($p<0.001$). The interaction of these two independent variables was also significant ($p<0.05$).

The mean and standard deviation values of the Vickers surface microhardness for each group are listed in Table 3. In the control group and all bleaching agents groups, Biodentine had significantly higher microhardness values compared to ProRoot MTA ($p<0.001$). For both CSCs, the lowest microhardness was observed in the HP group, and the HP group demonstrated significantly lower microhardness values than all other groups ($p<0.001$). Similarly, for both CSCs, the CP group exhibited significantly lower microhardness values compared to the SP-HP, SP-DW, and control groups ($p<0.001$). For both CSCs, significantly lower microhardness values were found in the SP-HP group compared to the control group ($p<0.05$). For ProRoot MTA, the difference between the SP-HP and SP-DW groups was not statistically significant ($p>0.05$). However, for Biodentine, the SP-HP group demonstrated significantly lower microhardness value than the SP-DW group ($p<0.05$). For both cements, the difference between the control and SP-DW groups was not statistically significant ($p>0.05$).

SEM Analysis

The SEM images of ProRoot MTA and Biodentine in the control, SP-DW, SP-HP, CP, and HP groups are illustrated in Fig. 2.

The SEM image of ProRoot MTA in the control group showed globular aggregate particles, rod-like, plate-shaped, and cubic crystals, and microchannels (Fig. 2A). In the SP-DW group, amorphous globular aggregate particles, microchannels, rod-like and plate-shaped crystals were evident (Fig. 2C). In the SP-HP group, selective erosion surrounding crystalline structures on the ProRoot MTA surface was evident by the presence of globular crystals and microchannels (Fig. 2E). The selective removal of matrix from the periphery of crystals resulted in a spongy appearance in the CP group. Cubic crystals, microchannels, and porosity were also observed in this group (Fig. 2G). In the HP group, extensive erosion, cracked surfaces, reticular pattern matrix structure, irregular needle-like crystals, and extensive porosity were formed on the ProRoot MTA surface due to superficial dissolution caused by hydrogen peroxide (Fig. 2I).

The SEM image of Biodentine in the control group showed cubic crystals as a common finding. Additionally, microchannels and plate-shaped crystals were also evident (Fig. 2B). In the SP-DW group, the specimen surface consisted of cubic crystals of irregular shape and size and microchannels. Lightly stratified structures were also noticed on the surfaces of the cubic crystals (Fig. 2D). In the SP-HP group, selective matrix loss around the crystalline structures, cubic and globular crystals, and microchannels were evident on the Biodentine surface (Fig. 2F). In the CP group, the Biodentine structure was characterized predominantly by cubic crystals, with rod-like crystals less frequently and mostly located between the cubic crystals. Furthermore, erosive surfaces over the cubic crystals and the presence of microchannels were observed (Fig. 2H). In the HP group, all cubic crystals dissolved due to the impact of hydrogen peroxide and the Biodentine surface consisted of amorphous globular aggregate particles, microchannels, and void depressions (Fig. 2J).

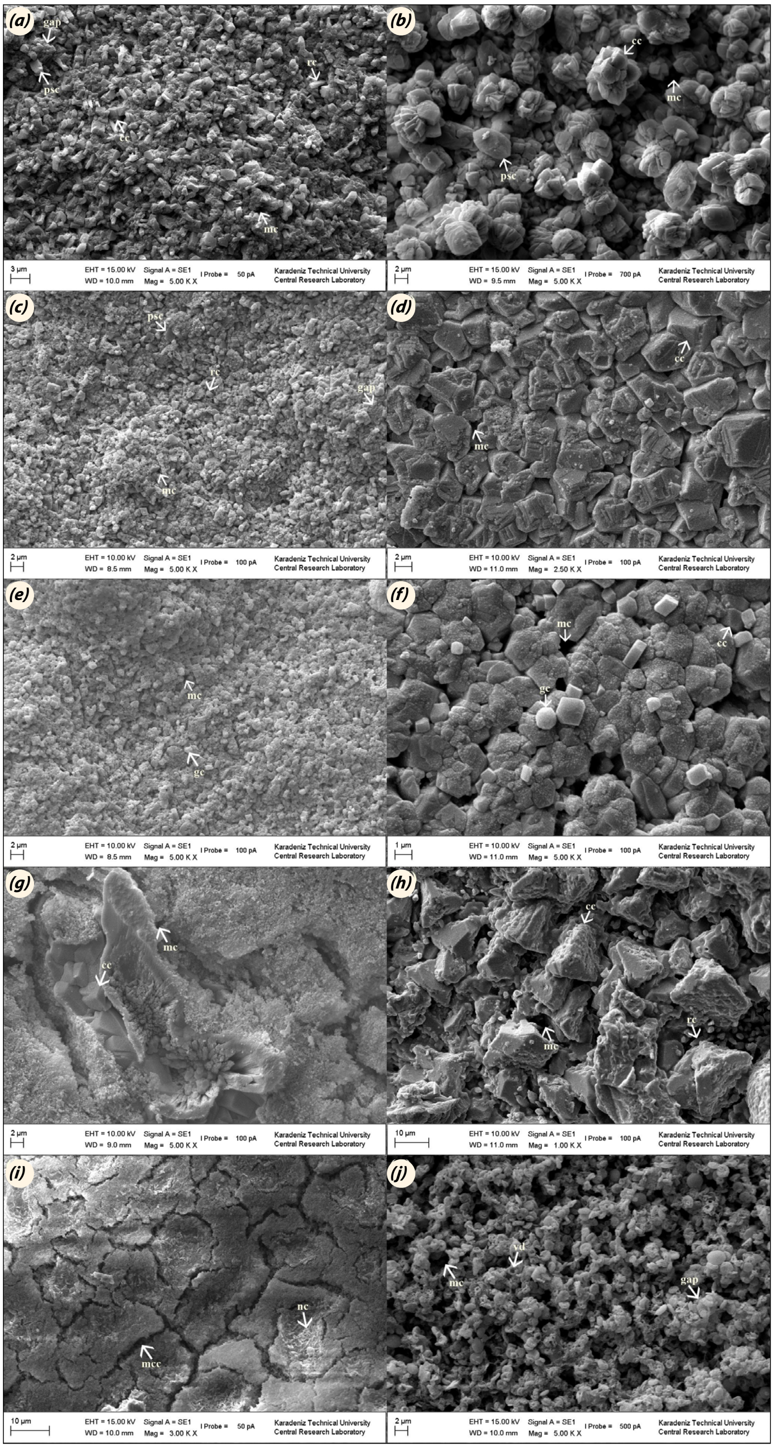

Fig. 2. SEM images at different magnifications (A, C, E, and G, 5000x; I, 3000x) of ProRoot MTA and (B, F, and J, 5000x, D, 2500x, and H, 1000x) of Biodentine. **(a)** globular aggregate particles (gap), plate-shaped crystals (psc), rod-like crystals (rc), cubic crystals (cc), and microchannels (mc) can be seen on the ProRoot MTA surface in the control group. **(c)** globular aggregate particles (gap), plate-shaped crystals (psc), rod-like crystals (rc), and microchannels (mc) can be seen on the ProRoot MTA surface in the SP-DW group. **(e)** globular crystals (gc) and microchannels (mc) can be seen on the ProRoot MTA surface in the SP-HP group. **(g)** cubic crystals (cc) and microchannels (mc) can be seen on the ProRoot MTA surface in the CP group. **(i)** microcracks (mcc) and needle-like crystals (nc) can be seen on the ProRoot MTA surface in the HP group. **(b)** cubic crystals (cc), plate-shaped crystals (psc), and microchannels (mc) can be seen on the Biodentine surface in the control group. **(d)** cubic crystals (cc) and microchannels (mc) can be seen on the Biodentine surface in the SP-DW group. **(f)** cubic crystals (cc), globular crystals (gc), and microchannels (mc) can be seen on the Biodentine surface in the SP-HP group. (H): cubic crystals (cc), rod-like crystals (rc), and microchannels (mc) can be seen on the Biodentine surface in the CP group. **(j)** globular aggregate particles (gap), microchannels (mc), and void depressions (vd) can be seen on the Biodentine surface in the HP group.

Discussion

In the present study, two different CSCs (ProRoot MTA and Biodentine) were exposed to a mixture of sodium perborate and distilled water, a mixture of sodium perborate and 3% hydrogen peroxide, carbamide peroxide, and hydrogen peroxide in order to mimic a clinical situation. According to our results, all bleaching agents, except for the mixture of sodium perborate and distilled water, decreased surface microhardness of both CSCs. Therefore, the first null hypothesis was partially rejected. In this study, the highest decrease in surface microhardness was determined for HP group for both CSCs, followed by CP and SP-HP groups, respectively. The number of studies examining the impact of bleaching agents on the surface microhardness of CSCs is quite limited (21,22). Consistent with the present study, Serin Kalay (2019) investigated the impact of hydrogen peroxide, carbamide peroxide, and a mixture of sodium perborate and distilled water on the surface hardness of ProRoot MTA and reported that both hydrogen peroxide and carbamide peroxide reduced the microhardness of MTA (21). However, Ahmadi and Meraji, in their study examining the effects of sodium perborate-distilled water mixture and hydrogen peroxide on the surface microhardness of MTA Repair HP, MTA Angelus, and Biodentine, stated that both bleaching agents reduced the surface microhardness of all cements, but a more pronounced effect was obtained with hydrogen peroxide (22).

It has been reported that the surface microhardness of CSCs decreases as a result of exposure to acidic pH (24–26). In the present study, the pH of 35% hydrogen peroxide tested was reported to be 5, the pH of 37% carbamide peroxide was 6-7 (21), and the pH of a mixture of sodium perborate and distilled water or hydrogen peroxide prepared at a ratio of 2:1 g/mL was greater than 7.4 (27). In the study, it was determined that surface microhardness decreased as the pH value decreased for both cements. Although the mixture of sodium perborate and hydrogen peroxide did not have an acidic pH, it caused a decrease in surface microhardness. Hydrogen peroxide may cause bubbling when it comes into contact with the surfaces of both CSCs (28), this oxygen bubbling may have changed the surface morphology of the cements. The low microhardness obtained in the SP-HP group may be due to the negative impact of hydrogen peroxide on the surface microstructure.

In this study, consistent with previous studies (29,30), it was determined that Biodentine had higher microhardness than ProRoot MTA in all groups. The increased microhardness observed in Biodentine can be explained by the low water-to-powder ratio facilitated by the presence of a plasticizing hydrosoluble polymer in the mixing liquid, thereby improving workability (9,15,16,31). In addition, one study has shown that a low water-to-powder ratio increases the mechanical strength of the material and leads to minimum porosity (32). In the present study, the higher microhardness values obtained with Biodentine may be attributed to the low water/powder in the structure of Biodentine.

Consistent with previous studies (21,28,33–35) the current study findings demonstrated that all bleaching agents altered the surface morphology of both ProRoot MTA and Biodentine. Therefore, the second null hypothesis was rejected. SEM images showed that more pronounced surface changes in the HP group than in the CP group, and in the CP group than in the SP-HP and SP-DW groups. It was observed that the crystalline structures in ProRoot MTA and Biodentine, which were evident in the control group, dissolved in the CP group, while the dissolution gradually intensified in the HP group. It has been reported that crystal clusters on the MTA surface dissolve in acidic pH environment, indicating structural weakening (24,25) and leading to a least stable cohesive structure (25). In this study, the observed decrease in surface microhardness in both HP and CP groups may be attributed to the dissolution of crystalline structures on the surfaces of the ProRoot MTA and Biodentine. It has been stated that the hardness value of ProRoot MTA decreases in acidic environment, resulting in a more porous microstructure of this material (24). It was reported that higher acidity in the solution resulted in more pronounced porosity in the ProRoot MTA samples (26). Additionally, it is well established that porosity generally shows a negative correlation with surface hardness; that is, as porosity decreases, surface hardness tends to increase (36). In the present study, SEM examination revealed greater porosity in specimens exposed to carbamide peroxide and hydrogen peroxide, but within the limitations of SEM, it was not possible to determine a precise and objective degree of porosity (26). The low microhardness values obtained in the HP and CP groups may be due to the negative effect of the porosity observed on the surfaces of the cements in these groups on the surface microhardness.

In the present study, SEM images revealed that the lower pH (pH 5 for HP and pH 6-7 for CP) associated with higher concentrations of hydrogen peroxide had a stronger impact on the surface structure of ProRoot MTA and Biodentine. Consistent with previous studies (28,35), these findings show that the effects of bleaching agents on the surface microstructure of CSCs depends on the hydrogen peroxide concentration. When exposed to moisture, 10% carbamide peroxide dissociates into 6.65% urea and 3.35% hydrogen peroxide (5). According to the manufacturer, 13.36% hydrogen peroxide was released from the

37% carbamide peroxide used in the current study. With the increase in hydrogen peroxide release, the negative effects of bleaching agents on the surfaces of CSCs have also increased.

In this study, more surface morphology changes were detected in the SP-HP group than in the SP-DW group. It is thought that hydrogen peroxide may have formed bubbling when it came into contact with the surfaces of both CSCs (28); this oxygen bubbling may explain the more pronounced surface changes observed in the SP-HP group compared to the SP-DW and control groups. Additionally, SP-DW group altered the surface morphology of both CSCs. Sodium perborate, a powdered oxidizing and whitening agent, remains stable under dry conditions but decomposes in the presence of water, warm air, or acid, producing sodium metaborate, nascent oxygen, and hydrogen peroxide (7,37). In this study, it was thought that the changes in surface morphology observed in the SP-DW group may have been caused by hydrogen peroxide released from sodium perborate.

The main limitation of this study is that it was conducted under in vitro conditions; however, the ideal approach is to evaluate restorative materials in clinical environments. Findings are limited to the brand and type of materials used in this study. Furthermore, this in vitro study did not include ageing procedures such as thermal and mechanical load cycling, and long-term effects of the materials were not assessed. Therefore, further studies are needed to determine the effects of bleaching agents and aging conditions on the surface properties of various CSCs.

Conclusion

All bleaching agents disturbed the surface morphology of ProRoot MTA and Biodentine. A substantial decrease in surface microhardness was found in all groups, except the mixture of sodium perborate and distilled water. Hydrogen peroxide induced the greatest decrease in surface microhardness, followed by carbamide peroxide and the mixture of sodium perborate and 3% hydrogen peroxide, respectively. Biodentine showed higher surface microhardness than ProRoot MTA in all groups. The present findings suggest that Biodentine may be preferred as a cervical barrier and a mixture of sodium perborate and distilled water may be the most conservative bleaching agent on CSC surfaces.

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ORIGINAL ARTICLE

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Effects of different irrigation agents on the bond strength of fiber posts to dentin structure

Gamze Durak Ozkilic, Sadullah Kaya

Department of Endodontics, Dicle University Faculty of Dentistry, Diyarbakır, Türkiye

Purpose: This study aims to investigate the push-out bond strength of fiber-reinforced posts following passive ultrasonic activation of the post space using EDTA, MTAD, Dual Rinse, and SmearOFF as final irrigation solutions, and to classify the associated modes of bond failure.

Methods: A total of 60 human mandibular premolar teeth were instrumented and obturated using a bioceramic-based root canal sealer. Post spaces were prepared using a fiber post drill set, maintaining 5 mm of the apical canal filling remained, and the samples were randomly divided into four groups (EDTA; MTAD; Dual Rinse; SmearOFF) (n=15). Intermittent passive ultrasonic activation protocols were applied to the final rinsing solutions. Fiber-reinforced posts were cemented into the post spaces using the self-adhesive resin cement Panavia SA Cement Universal.

Results: No statistically significant differences were found among the different final irrigation protocols applied. Although there was no statistical difference in the main effect, the main effect strength was highest in the EDTA group and lowest in the Dual Rinse group. Adhesive failure was the most frequently observed failure mode, while cohesive failures were observed at the lowest level.

Conclusion: EDTA, Dual Rinse, MTAD, and SmearOFF solutions have demonstrated comparable effects for post-space irrigation.

Keywords: Dual rinse; EDTA; SmearOFF; MTAD; push-out.

Introduction

Restoring endodontically treated teeth that have lost a significant portion of their coronal structure often necessitates the use of intra-radicular posts. Among the critical considerations during post-space preparation is the formation of a smear layer, which may hinder the bonding performance between resin-based cements and radicular dentin (1,2). To address this issue, clinicians commonly utilize sodium hypochlorite (NaOCl) in conjunction with chelating agents that facilitate the removal of inorganic remnants. One of the most frequently used agents for this purpose is ethylenediaminetetraacetic acid (EDTA), known for its effectiveness in eliminating the inorganic component of the smear layer. Nevertheless, prolonged exposure to EDTA may cause undesirable dentin erosion, especially when used beyond recommended durations (3).

MTAD, an irrigant composed of doxycycline, citric acid, and a detergent (polysorbate), has shown promise in effectively removing the smear layer, especially in the apical third of root canals. Compared to EDTA, MTAD has been

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Correspondence: Gamze Durak Özkılıç. Department of Endodontics, Dicle University Faculty of Dentistry, Diyarbakır, Türkiye
Tel: +90 539 – 6536327 e-mail: gamzdurk@gmail.com
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associated with reduced dentin erosion in the coronal and middle thirds. However, due to its lack of organic tissue dissolution capability, MTAD is typically used in conjunction with NaOCl (4,5). Previous in vivo studies suggest that sequential irrigation with 1.3% NaOCl followed by MTAD produces postoperative outcomes comparable to those achieved using 5.25% NaOCl and 17% EDTA (6). The widely recommended clinical approach involves a 20-minute rinse with NaOCl followed by a 5-minute application of MTAD (7).

Dual Rinse HEDP represents a newer generation of irrigants, offering a simplified regimen by combining etidronic acid with NaOCl (8). This formulation maintains the tissue-dissolving and antimicrobial capabilities of NaOCl for up to one hour and prevents smear layer formation during mechanical instrumentation (9). One of the key advantages of Dual Rinse is its efficiency; by eliminating the need to alternate between separate chelators and disinfectants, it reduces procedural time and complexity.

SmearOFF is a one-step irrigation solution composed of 18% EDTA and a small concentration of chlorhexidine (CHX) (<1%), formulated to remove the smear layer and provide disinfection simultaneously (10). It has a near-neutral pH of approximately 9 (11), and unlike conventional CHX solutions, has been shown not to form precipitates when used after NaOCl, eliminating the need for an intermediate rinse with saline or distilled water (10,12,13).

Panavia SA Cement Universal, the self-adhesive resin cement used in this study, integrates the application ease of conventional cements with the mechanical strength and esthetic benefits of resin cements (14). Its dual-cure nature enables reliable polymerization even in deeper regions where light penetration is limited. This one-step material requires no separate surface treatment, reducing technique sensitivity and minimizing the risk of post-operative sensitivity.

This study explores the influence of different final irrigation protocols—EDTA, MTAD, Dual Rinse, and SmearOFF—on the interfacial strength of glass fiber posts, as assessed through push-out analysis. Each solution was activated using passive ultrasonic activation (PUA) to improve debridement efficacy. The research also aims to classify the predominant failure modes observed during bond strength testing, offering additional insights into the adhesive interaction between dentin, fiber posts, and resin cements.

In this study, the null hypothesis (H_0) stated that the final irrigation protocol would have no statistically significant effect on the push-out bond strength of fiber posts to root canal dentin.

Materials and Methods

The present study, approved by the Local Ethics Committee of Dicle University Faculty of Dentistry (No: 2023/19, Date: 26/04/2023) and conducted according to the Declaration of Helsinki. All experimental procedures were conducted in the research laboratories of the Faculties of Dentistry at Dicle University and Selçuk University (Konya, Türkiye). A total of 60 human mandibular premolars extracted for periodontal reasons were used. Only teeth with single straight canals, mature apices, and no visible cracks or caries were included. Teeth with root fractures, previous endodontic treatment, resorption, or canal calcification were excluded. All procedures in this study were performed by a single operator. The sample size was determined by a priori power analysis using G Power software (version 3.1, University of Düsseldorf, Germany). Based on an alpha level of 0.05, a power of 0.80, and a medium effect size, the analysis indicated a requirement of 45 observations per solution group (15 samples × 3 root regions), totaling a minimum of 180 observations.

The working length for each specimen was determined using a #15 K-file (Dentsply Maillefer, Ballaigues, Switzerland) placed 1 mm short of the major apical foramen. No magnification system (such as dental loupes or an operating microscope) was used during working length determination or any other procedural step. Root canal instrumentation was performed with T-Endo MUST NiTi rotary files (Dentac, Istanbul, Türkiye), utilizing M25 (25/06) and M40 (40/04) file sequences in combination with an Ai-motor endomotor (Woodpecker, Guilin, China). During canal shaping, 2 mL of 5% NaOCl (Microvem, Istanbul, Türkiye) was delivered following each file change using a 27-gauge open-ended syringe (Ultradent, South Jordan, UT, USA). The total NaOCl volume per canal amounted to 10 mL. Following chemomechanical instrumentation, 2 mL of 17% EDTA (Promida Ltd., Eskişehir, Türkiye), was applied to each canal for one minute. Subsequently, a final rinse was performed using 3 mL of 5% NaOCl. To facilitate irrigant activation, the final NaOCl rinse was subjected to passive ultrasonic agitation using an ultrasonic tip (Irrisafe, #20–21; Satelec, Merignac-Cedex, France) positioned 1 mm short of the established working length. Activation was carried out for 30 seconds, at a frequency of 30 kHz and medium power setting, as recommended by the manufacturer, after which the canals were rinsed with distilled water to eliminate any residual irrigant.

The canals were then dried using sterile absorbent paper points (President Dental, Munich, Germany). Obturation was performed with the single-cone technique using gutta-percha cones (Dentsply Maillefer, Ballaigues, Switzerland) and a bioceramic-based root canal sealer (AH Plus Bioceramic Sealer; Dentsply Sirona, Erlangen, Germany). Coronal orifices were sealed with a temporary restorative material (Cavit; 3M ESPE, Seefeld, Germany), and the teeth were stored in distilled water at 37°C for one week to ensure complete setting of the sealer prior to post-space preparation.

Post gaps measuring 9 mm in depth were created using a fiber post drill system, while ensuring that 5 mm of apical filling material remained intact. Following preparation, the 60 specimens were randomly assigned to four experimental groups, each comprising 15 samples.

• Dual Rinse (Medcem GmbH, Weinfelden, Switzerland) group: 10 mL Dual Rinse, 1 min PUA

• EDTA group: 5 mL 5% NaOCl + 5 mL 17% EDTA, 1 min PUA

• MTAD (Dentsply Tulsa Dental Specialties, Tulsa, OK, USA) group: 5 mL 1.3% NaOCl + 5 mL MTAD, 1 min PUA

• SmearOFF (Vista Dental Products, Racine, WI, USA) group: 5 mL 5% NaOCl + 5 mL SmearOFF, 1 min PUA

The PUA protocol involved intermittent application, with 2.5 mL of solution followed by 30 seconds of activation, repeated twice.

After drying with absorbent paper points (President Dental, Munich, Germany), fiber posts (Exacto No: 2, Angelus, Londrina, PR) were cemented using Panavia SA Cement Universal (Kuraray, Okayama, Japan). The resin cement was applied using an intra-canal tip, excess cement was removed, and polymerization was performed using an LED curing unit (Bluephase 20i, Ivoclar Vivadent, Liechtenstein) at 1200 mW/cm^2 for 20 seconds.

The samples were embedded in cold acrylic resin (Meliodent Rapid Repair, Heraeus-Kulzer) using cylindrical plastic molds, ensuring that the coronal surface of the tooth was level with the mold surface. Using a Microcut device (Microcut 201; Metkon, Bursa, Türkiye), an initial 1 mm thick cervical section was removed. Then, three consecutive transverse sections of 2.0 ± 0.1 mm thickness were obtained from each root. Specimens were categorized into apical, middle, and cervical thirds, and mounted on a mechanical testing device (Lloyd LS series; Ametek Inc., Lloyd Instruments, Fareham, UK), with the apical end oriented upward.

To dislodge the fiber posts from the canals, a force was applied using custom push-out pins with diameters of:

• 0.8 mm for the cervical region,

• 0.5 mm for the middle region,

• 0.3 mm for the apical region.

The loading speed was set to 1 mm/min.

Fracture load values were measured in Newtons (N) using Nexygen software integrated with the Lloyd LRX testing system (Fareham, UK). The bond strength was then calculated by converting the maximum load values to Megapascals (MPa) using the following formula:

$$\text{Bond strength (MPa)} = \frac{\text{Maximum load (N)}}{\text{Bonding area of the fiber post}}$$

For each section, the bonding area of the fiber post (mm2) was calculated using the formula:

Bonding area=2πrh

r represents the radius of the fiber post,

h represents the thickness of the section (in mm),

π (pi) was taken as 3.14.

The specimens subjected to the push-out bond strength test were subsequently evaluated under a stereomicroscope (Axiocam MRC, Carl Zeiss, Germany) at 25× magnification to determine the mode of failure.

Statistical Analysis

Statistical analyses were performed using IBM SPSS Statistics, Version 23 (IBM Corp., Armonk, NY, USA) and JAMOVI, Version 2.3.28 (Sydney, Australia). The Shapiro-Wilk test was utilized to evaluate the normality of data distribution. Two-Way Robust ANOVA from the Walrus package was utilized to compare bond strength across different irrigation solutions and regions, with Bonferroni correction applied for multiple comparisons. Final data were presented as median values accompanied by the lowest and highest ranges. A significance level of $p<0.050$ was considered.

Results

A statistically significant interaction was observed between the irrigation solution and root region ($p<0.001$) (Table 1). The highest median bond strength was recorded in the coronal region with Dual Rinse (7.92 MPa), while the lowest was in the apical region with Dual Rinse (1.01 MPa). However, statistical analysis revealed no meaningful variation across the irrigation protocols or root canal regions ($p>0.050$).

The failure modes observed following the push-out test, categorized by irrigation solution, are presented as frequencies and percentages in Table 2.

Table 1. Descriptive statistics (median, minimum, and maximum values) of bond strength according to irrigation solution and region, along with multiple comparison results

Irrigation solution	Region			
	Apical	Middle	Coronal	Total
Dual Rinse	1.01 (0.65 – 1.42)[A]	6.51 (1.48 – 17.79)[AB]	7.92 (2.97 – 19.58)[B]	4.43 (0.65 – 19.58)
EDTA	5.14 (0.1 – 23.81)[AB]	3.05 (1.33 – 13.27)[AB]	5.95 (1.43 – 47.92)[AB]	5.14 (0.1 – 47.92)
MTAD	3.12 (0.13 – 26.77)[AB]	6.54 (1.04 – 17.04)[AB]	4.89 (1.34 – 28.17)[AB]	4.89 (0.13 – 28.17)
SmearOFF	3.59 (0.78 – 28.01)[AB]	3.9 (1.1 – 13.48)[AB]	7.6 (1.33 – 19.7)[AB]	5 (0.78 – 28.01)

[A-B]: Interactions with the same letter indicate no significant difference; Median (Minimum - Maximum).

Table 2. Frequency and percentage distribution [n(%)] of adhesive, cohesive, and mixed failure types for each solution.

Failure types	EDTA	MTAD	SmearOFF	Dual Rinse
Adhesive	32 (7.1%)	28(62.2%)	21 (46.6%)	35 (77.7%)
Cohesive	3 (6.6%)	5 (11.1%)	8 (17.7%)	1 (2.2%)
Mixed	10(22.2%)	12(26.6%)	16 (35.5%)	9 (20%)

Discussion

The ease of root canal sealer removal during post-space preparation is critical for the proper cementation and retention of fiber posts. Effective decontamination of the dentin surface during canal preparation significantly contributes to improved bond strength. In a comparative study, Vilas et al. (15) evaluated the adhesion of fiber posts in canals filled with Endofill, EndoSequence BC, and AH Plus sealers. Their findings showed that AH Plus was more easily removed from the canal walls compared to the other sealers, resulting in higher bond strength values for fiber post cementation. The present study used AH Plus Bioceramic Sealer, an improved and advanced version of AH Plus. This research is novel because AH Plus Bioceramic Sealer is a contemporary material that has not yet been widely studied in cavities prepared for post-space.

Evidence suggests that a one-week waiting period after root canal obturation positively affects the bond strength of fiber posts and resin cement (16,17). Therefore, in our study, fiber post-placement was performed after a one-week waiting period to ensure the complete setting of the root canal sealer.

The resin cement used during fiber post application is intended to ensure seamless integration between the post and the tooth, creating a structure resistant to forces and forming an effective barrier against microleakage (18). Therefore, selecting an appropriate cement is crucial for achieving a successful bond. Self-adhesive resin cements are widely favored for their simplified application protocol, as they reduce technique sensitivity and eliminate the need for separate bonding agents or surface conditioning steps (19). However, during post-cementation, the progressive reduction in light penetration towards the apical region can result in insufficient photoactivation, leading to polymerization issues (20). To mitigate these drawbacks, our study utilized Panavia SA Cement Universal, a dual-cure self-adhesive resin cement that ensures reliable polymerization even in deeper regions.

The integrity of the interface among dentin, fiber post, and resin cement plays a pivotal role in determining the retention of fiber posts (21) Clearing the debris-rich layer that accumulates along canal walls during post instrumentation is widely regarded as a key step in promoting retention and optimizing the adhesive interface. If not adequately removed, the smear layer can occlude dentinal tubules, impair adhesion, and ultimately compromise the micromechanical interlocking between the post and the tooth structure (22,23). Consequently, meticulous cleaning of the root canal dentin surface is essential prior to fiber post cementation to ensure optimal bonding (23). The standard protocol for smear layer removal involves the application of 17% EDTA following NaOCl irrigation (24). Initially, NaOCl dissolves organic tissues within the root canal, while subsequent EDTA irrigation targets inorganic debris, effectively cleansing the canal walls and restoring the patency of dentinal tubules by eliminating smear layer residues (25).

The role of ultrasonic systems in improving the efficacy of irrigants during smear layer removal has been highlighted in multiple studies. Guo et al. (26) emphasized that ultrasonic activation serves as a beneficial adjunct, contributing significantly to enhanced canal cleanliness. Supporting this, Dioguardi et al. (27) demonstrated that passive ultrasonic activation (PUA) facilitates apical debridement by producing high-frequency acoustic turbulence and cavitation within the canal. Kuah et al. (28) further observed that a 60-second ultrasonic activation of 17% EDTA resulted in superior removal of smear remnants from the apical third. The performance of the EDTA group in the present study aligns with these previously reported findings.

Although no statistically significant difference was observed among regions within the EDTA group, the apical region demonstrated higher bond strength than the middle region. However, in their studies, Gu and Guo suggested that PUA has a similar effect to conventional irrigation techniques (22,26). The variability in outcomes with PUA may be attributed to differences in experimental setups and material choices. A control group without PUA was not included in the current study, as the primary aim was to compare the relative performance of different final irrigants under standardized activation conditions. The omission of an unactivated control group allows a focused evaluation of irrigant efficacy under clinically relevant agitation protocols.

Tay et al. (29) reported that MTAD exerts a more pronounced demineralizing effect on sound intraradicular dentin compared to EDTA, resulting in collagen matrices that are approximately 1.5 to 2 times thicker than those produced by EDTA. These enhanced matrices promote dentin hybridization with hydrophilic methacrylate-based cements without the need for phosphoric acid etching or using self-etch resin cement. While previous studies have indicated that root canals irrigated with MTAD and obturated with AH Plus achieve excellent coronal sealing (30), the thicker intraradicular collagen matrices generated by MTAD may compromise resin infiltration, leading to potential bonding deficiencies (31). Unlike the open leakage typically observed in the coronal region, incomplete resin infiltration within these matrices may result in nanometer-scale leakage (29). Additionally, Yurdagüven et al. (32) found that MTAD application significantly reduces the bonding strength of self-etch adhesives to coronal dentin. Consistent with these findings, our study demonstrated that the MTAD group presented lower bond strength in the coronal region compared to the middle region. This outcome is likely attributed to the intraradicular collagen matrices formed by MTAD, which may have hindered resin infiltration, particularly when using self-adhesive cement.

Erik et al. (11) reported that irrigation with SmearOFF significantly reduced post-bond strength. However, in our research, SmearOFF demonstrated the second-highest bond strength after EDTA. This difference may be attributed to the chlorhexidine (CHX) content in SmearOFF, which acts as a matrix metalloproteinase (MMP) inhibitor, preventing collagen degradation at the bonding interface. The suppression of collagen matrix degradation may have been a contributing factor to the improved bond strength documented in our findings (33).

According to Erik et al. (11), post-space irrigation using Dual Rinse resulted in apical and middle region bond strength values comparable to those attained with EDTA. Unlike some earlier reports, the present study showed that the coronal and middle thirds of the root canals exhibited the highest bond strength values. Although no statistically significant differences were identified among the final irrigation agents evaluated, a notable difference was detected between the coronal and apical segments in specimens treated with Dual Rinse. In light of these outcomes, the null hypothesis (H_0) was only partially supported.

Several factors may account for the progressive decline in bond strength observed from the coronal toward the apical region. Factors contributing to this decline include the restricted penetration of irrigation solutions into the apical third, largely attributed to insufficient solution volume, and the heightened anatomical complexity of the apical root canal system. In addition, the crown-down instrumentation technique leads to a higher accumulation of dentin debris within the apical third tubules, potentially compromising adhesion. The gradual reduction in both the quantity and surface area of dentinal tubules in the apical region also plays a significant role in the observed decline in bond strength (34–36).

Beyond tubular patency and dentin morphology, the choice of self-adhesive resin cement in our study also played a pivotal role in the outcomes. This observation is in accordance with the findings of Topçu et al. (37), who noted a lower bond strength in the apical region, primarily attributed to the superior accessibility of the coronal third for both adhesive application and light-curing energy. Moreover, prior studies have suggested that both hydrostatic conditions and the efficiency of adhesive light activation are impaired in the apical third, which is regarded as a key factor contributing to the reduced bond strength in this area (38). The bond failure modes were examined under 25× magnification using a stereomicroscope to assess the characteristics of interfacial disruption. Analysis revealed that adhesive failure was the predominant mode observed across all specimens.

The adhesive interface is commonly recognized as the most vulnerable area post-cementation, with adhesive failure between dentin and resin cement representing a critical issue in push-out bond strength evaluations (39). This study utilized Panavia SA Cement Universal, adhering strictly to the manufacturer's guidelines, without supplementary surface treatment. According to the manufacturer, Panavia SA is a one-step, user-friendly cement that provides reliable adhesion to diverse materials without requiring an additional primer. Nonetheless, the results of our study suggest that this cement did not attain optimal bonding efficacy. Fiber posts were cemented one-week post-root canal obturation in our investigation. Previous studies by Yuanli and Alsubait revealed that fiber posts cemented immediately following root canal treatment in teeth obturated with bioceramic sealers revealed enhanced bond strength (40,41). As a result, the one-week delay before post-cementation in our study may have negatively influenced the bonding performance, potentially leading to adhesive failure.

Despite the strengths of this study, several limitations should be acknowledged. The lack of standardization in NaOCl concentration among groups, use of a single resin cement type, and deviation from manufacturer-recommended MTAD application times may have introduced bias. Additionally, omitting distilled water or NaOCl rinsing after EDTA, as well as the unassessed thermal effects of passive ultrasonic activation on periodontal tissues, restrict the generalizability of these results. Further studies are needed to establish safe and effective PUA protocols under clinically relevant conditions.

Conclusion

This study highlights the substantial impact of post-space irrigation protocols on the bond strength of fiber posts to root canal dentin. Although all tested final irrigation solutions—EDTA, MTAD, Dual Rinse, and SmearOFF—yielded comparable overall bond strength outcomes when combined with passive ultrasonic activation, region-specific discrepancies were evident. Notably, the Dual Rinse group exhibited a statistically significant decrease in bond strength in the apical third compared to the coronal region. The predominance of adhesive failure modes underscores the susceptibility of the resin–dentin interface to variations in surface treatment. These findings suggest that, while the irrigation solutions appear similarly effective on a general level, their performance may vary across different regions of the root canal, particularly in the apical third, where reduced adhesion continues to pose clinical challenges. Therefore, further studies are necessary to clarify the physicochemical characteristics of these irrigation solutions and their interactions with dentinal substrates, especially in the anatomically complex apical areas of the root canal system.

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ORIGINAL ARTICLE

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Evaluation of the effectiveness of different irrigation activation methods in removing calcium hydroxide from root canals

Nursima Eken,[1] Dilek Türkaydın[2]

[1]Department of Endodontics, Kafkas University Faculty of Dentistry, Kars, Türkiye
[2]Department of Endodontics, Marmara University Faculty of Dentistry, Istanbul, Türkiye

Purpose: The aim was to evaluate the effectiveness of different irrigation activation methods in removing calcium hydroxide ($Ca(OH)_2$) from two different root canal isthmuses (apical and middle levels) created using three-dimensional (3D) modelling.

Methods: In this in vitro study, 150 acrylic blocks were divided into 10 groups (n=15). Models fabricated and filled with pure injectable $Ca(OH)_2$ paste (UltraCal XS, Ultradent, South Jordan, UT). Five irrigation activation groups were established (conventional needle irrigation (CNI), EDDY activation, passive ultrasonic activation, XP Endo Finisher activation and Er,Cr:YSGG laser activation). The amount of residual $Ca(OH)_2$ in the root canal isthmus was evaluated with a stereomicroscope at ×10 magnification. All procedures were performed by a single operator. The area containing $Ca(OH)_2$ was subtracted from the total area measurement and the cleaning percentage and area calculation were made using the Image J program. The obtained data were recorded in the Microsoft Excel program, and IBM SPSS v29 package program was used for analysis and visualization of the data.

Results: Er,Cr:YSGG laser showed significantly lower amount of $Ca(OH)_2$ remnants compared to other methods ($p<0.001$). In the apical isthmus region, EDDY was the least effective method, while in the middle isthmus region, the CNI method was the least effective.

Conclusion: Er,Cr:YSGG laser-activated irrigation technique demonstrated superior efficacy in the removal of $Ca(OH)_2$ from root canal isthmus regions than other activation methods. 3D modelling enabled the comparison of irrigation activation methods in a standardized manner.

Keywords: Calcium hydroxide removal; EDDY; Er, Cr: YSGG; irrigation activation; isthmus; passive ultrasonic activation; XP finisher.

Introduction

Interim intracanal medication commonly relies on calcium hydroxide ($Ca(OH)_2$) for antimicrobial control. If residues remain, they may hinder sealer bonding and lead to greater apical leakage—factors associated with endodontic treatment failure (1). Numerous studies have explored different irrigants and activation techniques to improve $Ca(OH)_2$ removal (2-4). The most common approach involves shaping the root canal with a master apical file, followed by continuous irrigation activation with sodium hypochlorite (NaOCl) and ethylenediaminetetraacetic acid (EDTA). Despite this, there is no consensus on the most effective method for $Ca(OH)_2$ removal (5).

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Correspondence: Nursima Eken. Department of Endodontics, Kafkas University Faculty of Dentistry, Kars, Türkiye
Tel: +90 538 – 567 33 35 e-mail: nursimaeken21@gmail.com
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The isthmus, defined as a slender corridor connecting adjacent canals, is a common and complex morphology in maxillary premolars and mandibular first molars (6). Traditional methods are often inadequate due to intracanal irregularities such as isthmuses. The locations of the isthmuses are important in the effectiveness of the irrigation activation method. Studies have demonstrated that isthmuses in the coronal and middle thirds of the root canal are generally easier to clean, whereas cleaning efficacy decreases in the apical region. This observation has been consistent regardless of the irrigation method employed (7). Additionally, the width and length of the isthmus influence its cleanability; short and wide isthmuses are the easiest to clean, whereas narrow isthmuses are the most challenging. It is emphasized that width is a more critical anatomical parameter compared to length (7). For this reason, both the location and the morphological features of the isthmus directly affect the success of cleaning in root canal treatment (7,8).

Although numerous studies have compared irrigation activation methods for cleaning isthmuses, there is still no definitive consensus on which technique is most effective (7). High-frequency sonic irrigation (EDDY) and laser-activated irrigation (LAI) consistently demonstrate superior debris and biofilm removal in isthmus models, often outperforming passive ultrasonic irrigation (PUI), sonic activation, and conventional needle irrigation (CNI), especially in the coronal and middle thirds of the canal (9). However, all methods show reduced efficacy in the apical third, and none can guarantee complete cleaning in every anatomical scenario (10). Thus, while activation methods enhance isthmus cleaning compared to CNI, the search for an optimal, consensus-based protocol continues. Therefore, this in-vitro study aims to evaluate the effectiveness of five different activations methods including CNI, sonic activation, PUI, LAI, and XP-Endo Finisher (XP, FKG Dentaire, La Chaux-de-Fonds, Switzerland) in removing $Ca(OH)_2$ from root canals with standardized artificial isthmuses at two different levels. The first hypothesis is that laser activation will be more effective than other activation methods. The second hypothesis is that middle isthmuses can be cleaned more effectively than apical isthmuses.

Materials and Methods

In order to investigate the effects of acrylic blocks (located in the middle and apical thirds of the isthmus) and activation methods (CNI, laser activation, ultrasonic activation, and activation with EDDY and XP Finisher), a two-way factorial ANOVA was employed. Based on calculations using G*Power version 3.1.9.4, with a medium to large effect size (f=0.40), an alpha level of 0.05, and a power of 0.95, the minimum required sample size per group was 14 (11,12). Given that there are ten groups, the total sample size required was 140. This study utilized a total of 150 acrylic root canal models (75 middle isthmus, 75 apical isthmus). Models were designed using Chitubox V1.9.5 software and produced with a 3D printer (Sonic Mega 8K) (Fig. 1).

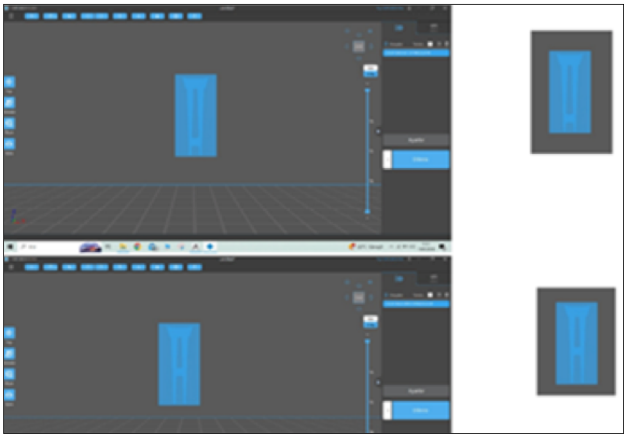

Fig. 1. Visualization of 3D printed root canals isthmuses using Chitubox V1.9.5.

The acrylic block models used in this study were designed to simulate root canal isthmus morphology in two distinct configurations. In the models with a middle-level isthmus, the isthmus area was designed with dimensions of 4 mm in height, 5 mm in length, and 0.4 mm in width. In the models with an apical isthmus, the corresponding dimensions were 2 mm in height, 3 mm in length, and 0.15 mm in width. All models were standardized with a root canal length of 16 mm, a taper of 0.06, and an apical diameter of 0.30 mm (11).

Injectable calcium hydroxide was applied to acrylic models with apical and middle isthmuses (Fig. 2A, 2B). After homogeneity was verified under dental operation microscope, canal orifices were sealed with teflon tape and temporary restoration material (Cavit-W, 3M Espe, Seefeld, Germany) and stored at 37°C in 100% humidity for 1 week. Samples were divided into 5 groups according to the irrigation activation method:

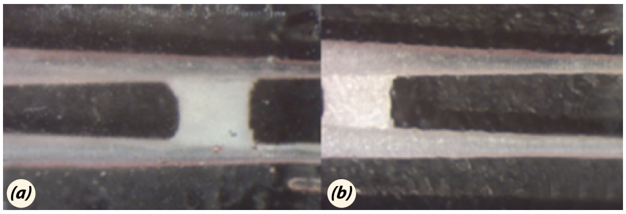

Fig. 2. Representative images of intra-isthmuses material removel. **a)** Apical isthmus filled $CaOH_2$; **b)** Middle isthmus filled $Ca(OH)_2$.

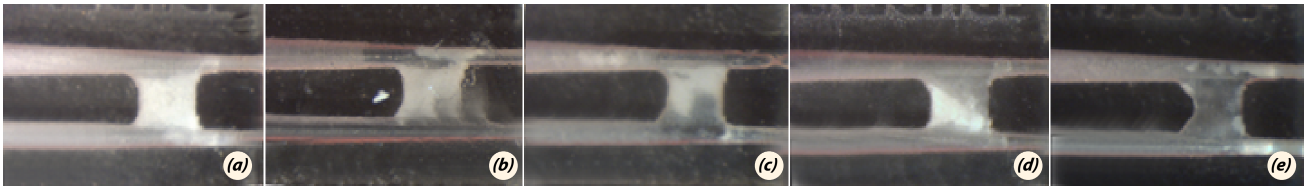

Fig. 3. Apical isthmuses after irrigation activation methods. **a)** CNI activation; **b)** EDDY activation; **c)** PUI activation; **d)** XP Endo Finisher activation; **e)** Laser activation.

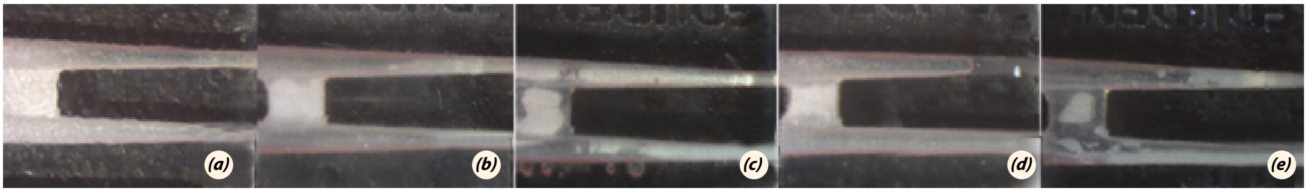

Fig. 4. Middle isthmuses after irrigation activation methods. **a)** CNI activation; **b)** EDDY activation; **c)** PUI activation; **d)** XP Endo Finisher activation; **e)** Laser activation.

Group 1: CNI (n=30) (Fig. 3A; Fig. 4A)

Group 2: Activation with EDDY (n=30) (Fig. 3B; Fig. 4B)

Group 3: Passive ultrasonic activation (n=30) (Fig. 3C; Fig. 4C)

Group 4: Activation with XP Endo Finisher (n=30) (Fig. 3D; Fig. 4D)

Group 5: Activation with Er,Cr:YSGG laser (n=30) (Fig. 3E, Fig. 4E)

A standard irrigation protocol was applied to all groups: Irrigation was performed for 120 seconds with 6 mL 5% NaOCl, 2 mL distilled water, 6 mL 17% EDTA, and finally 10 mL distilled water (6). The relevant activation method in each group was used according to the manufacturer's instructions. All procedures were performed by a single operator. All samples were dried with paper points to working length. Images were taken at x10 magnification using an AxioCamERc5 camera (Zeiss) attached to a stereomicroscope (Stemi 2000-C; Zeiss, Gottingen, Germany) (Fig. 3; Fig. 4). The obtained images were processed using Image J software (Image J, US National Institutes of Health, Bethesda, MD, USA) to mark the total size of the isthmus and Ca(OH)2 residues (Fig. 5). The area of each was calculated in pixels using the computer program. During the assessment of residual Ca(OH)2, the experimental groups were kept blinded from the evaluator.

The formula for calculating the percentage of $Ca(OH)_2$ removal from artificial isthmuses is: Removal Percentage (%) = [(Initial amount of $Ca(OH)_2$- Remaining amount after procedure) / Initial amount of Ca(OH)2] × 100. This formula is widely used in studies evaluating the effectiveness of different irrigation techniques for removing $Ca(OH)_2$ from root canal isthmuses (11).

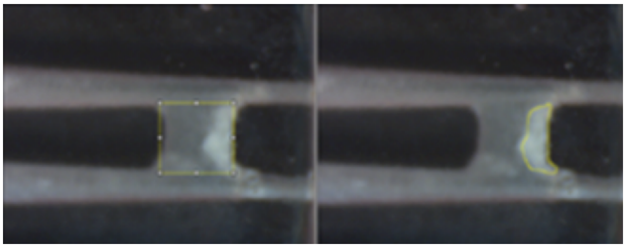

Fig. 5. Image calculation of residual $Ca(OH)_2$ using Image J software.

The measurements were performed blindly by two independent operators. The recorded values were saved in an Excel program. In this study, the percentages of residual $Ca(OH)_2$ in the acrylic models' isthmuses were compared based on the scoring system (9):

Score 1: <20%, Score 2: Between 20% and 60%, Score 3: >60%.

Statistical Analyses

Statistical analyses were performed using IBM SPSS v29 (IBM Corporation, Armonk, New York, USA) package program. Chi-Square Test was used for comparison of categorical variables, Mann-Whitney U Test for two-group comparisons, and Kruskal Wallis Test for comparisons of more than two groups. The level of statistical significance was accepted as $p<0.05$.

Results

The quantitative and qualitative outcomes of the $Ca(OH)_2$ removal process are summarized in Tables 1–3. Table 1 presents the initial pixel values representing the total volume of isthmuses filled with $Ca(OH)_2$, the post-activation residual pixel measurements, and the cor-

Table 1. Initial and post-activation remaining calcium hydroxide amounts according to irrigation activation methods (pixels)

Irrigation activation method	Initial value Median (25th–75th percentile)	Post-activation value Median (25th–75th percentile)	Reduction percentage (%) Median (25th–75th percentile)
Conventional (n=31)	97.104 (94.484–101.370)	52.682 (41.510–59.315)	48.2 (40.6–57.0) A
EDDY (n=30)	100.864 (97.792–107.844)	42.575 (27.936–55.685)	57.0 (45.3–73.3) B
XP Finisher (n=31)	94.392 (90.262–98.698)	34.010 (28.033–37.803)	64.1 (60.4–70.7) C
Ultrasonic (n=30)	93.500 (91.680–97.520)	32.859 (29.611–42.348)	63.9 (57.8–70.8) D
Er,Cr:YSGG (n=30)	94.270 (89.680–97.920)	5.645 (2.104–16.177)	93.7 (82.8–97.9) E

EDDY: High-frequency sonic irrigation. Kruskal–Wallis Test: Initial value: $p>0.05$; Post-activation value: $p<0.001$; Reduction percentage: $p<0.001$. Multiple comparisons (letters): E > A, B, C, D; A < C, D, E.

Table 2. Initial and post-activation remaining calcium hydroxide amounts according to isthmus location (pixels)

Irrigation activation method	Measurement Median (25th–75th percentile)	Apical isthmus Median (25th–75th percentile)	Middle isthmus	p
Conventional (n=31)A	Initial value	94.672 (92.252–100.966)	99.960 (96.432–101.370)	p>0.05
Conventional (n=31)A	Post-activation	50.480 (41.480–57.115)	52.941 (41.772–61.640)	
Conventional (n=31)A	Reduction percentage (%)	46,6 (55,0–43,4)	44,7 (56,6–39,1)	
EDDY (n=30)B	Initial value	100.640 (96.348–107.516)	101.088 (99.926–108.532)	
p<0.001				
EDDY (n=30)B	Post-activation	55.685 (51.321–58.867)	27.936 (19.210–35.735)	
EDDY (n=30)B	Reduction percentage (%)	45,3 (46,7–45,2)	72,3 (80,7–67,0)	
XP Finisher (n=31)C	Initial value	90.240 (88.160–91.512)	98.648 (96.672–100.528)	p>0.05
XP Finisher (n=31)C	Post-activation	33.939 (25.777–35.360)	34.010 (32.262–38.747)	
XP Finisher (n=31)C	Reduction percentage (%)	62,3 (70,7–61,3)	65,5 (66,6–61,4)	
Ultrasonic (n=30)D	Initial value	93.696 (92.580–96.372)	93.304 (90.288–97.712)	
p<0.001				
Ultrasonic (n=30)D	Post-activation	42.348 (32.883–46.859)	29.708 (24.835–32.858)	
Ultrasonic (n=30)D	Reduction percentage (%)	54,8 (64,4–51,3)	68,1 (72,4–66,3)	
Er,Cr:YSGG (n=30)E	Initial value	89.680 (85.616–91.232)	97.812 (95.510–99.762)	p>0.05
Er,Cr:YSGG (n=30)E	Post-activation	5.473 (707–14.971)	10.219 (3.236–18.208)	
Er,Cr:YSGG (n=30)E	Reduction percentage (%)	93,8 (99,1–83,5)	89,4 (96,6–81,7)	

EDDY: High-frequency sonic irrigation. Kruskal–Wallis Test: $p<0.001$; E > A, B, D. Kruskal–Wallis Test: $p<0.001$; B, E > A.

responding percentage reductions for each group. There was no significant difference between groups in terms of initial $Ca(OH)_2$ amount ($p>0.05$). When examining the remaining $Ca(OH)_2$ amount after irrigation activation, the lowest median value was observed in the Er,Cr:YSGG laser group, while the highest value was observed in the CNI group (5,645; 52,682; respectively). The difference between groups was found to be statistically significant ($p<0.001$) (Table 1).

Table 1 presents the percentage reduction of $Ca(OH)_2$ in isthmuses according to the irrigation activation method used. The highest percentage of reduction was observed with the Er,Cr:YSGG laser method, while the lowest was with the CNI method (93.7%; 48.2%; respectively). The difference in reduction percentages between these methods was statistically significant (Mann Whitney U Test; $p<0.001$) (Table 1).

According to the results of pairwise comparisons performed with Bonferroni correction, the residual $Ca(OH)_2$ value in the Er,Cr:YSGG method was found to be lower than that of the other methods, and this difference was statistically significant ($p<0.001$) (Table 1).

Table 2 provides a location-specific comparison of the initial and post-irrigation pixel values of $Ca(OH)_2$ in the apical and middle isthmuses, along with the corresponding reduction percentages. The highest median reduction after irrigation activation was observed in both the apical and middle isthmuses with the Er,Cr:YSGG method (93.8% and 89.4%, respectively), while the lowest median reduction was observed in the apical isthmus with the EDDY

Table 3. Scoring of remaining calcium hydroxide amounts

Irrigation activation method	All models Score 1 (<20%)	All models Score 2 (20–60%)	All models Score 3 (>60%)	Apical isthmus Score 1 (20–60%)	Apical isthmus Score 2 (20–60%)	Apical isthmus Score 3 (>60%)	Middle isthmus Score 1 (<20%)	Middle isthmus Score 2 (20–60%)	Middle isthmus Score 3 (>60%)
Conventional (n=31)	0	24 (77.4%)	7 (22.6%)	0	13 (81.3%)	3 (18.8%)	0	11 (73.3)	4 (26.7)
EDDY (n=30)	4 (13.3%)	25 (83.3%)	1 (3.3%)	0	14 (93.3%)	1 (6.7%)	4 (26.7)	11 (73.3)	0
XP Finisher (n=31)	0	30 (96.8%)	1 (3.2%)	0	14(100.0%)	0	0	16 (94.1)	1
Ultrasonic (n=30)	2 (6.7%)	28 (93.3%)	0	0	15 (100.0%)	0	2 (13.3)	13 (86.7)	0
Er,Cr:YSGG (n=30)	24 (80%)	6 (20%)	0	13 (86.7%)	2 (13.3%)	0	11 (73.3)	4 (26.7)	0

EDDY: High-frequency sonic irrigation. Chi-Square Test: $p<0.001$ (All models). Chi-Square Test: $p<0.001$ (Apical isthmus). Chi-Square Test: $p<0.001$ (Middle isthmus) Three scores were given according to the percentage of remaining calcium hydroxide in acrylic models:. Score 1: Isthmus with less than 20% remaining calcium hydroxide. Score 2: Isthmus with 20–60% remaining calcium hydroxide. Score 3: Isthmus with more than 60% remaining calcium hydroxide.

method and in the middle isthmus with the CNI method (45.3% and 44.7%, respectively). The Kruskal-Wallis test revealed that this difference was statistically significant for both isthmuses ($p<0.001$) (Table 2).

Table 3 presents the categorical score-based assessment of the residual $Ca(OH)_2$ levels (score 1: <20%, score 2: 20–60%, score 3: >60%). In the samples treated with the Er,Cr:YSGG method, 80% of the specimens exhibited less than 20% residual $Ca(OH)_2$ after the procedure. Conversely, none of the samples subjected to the CNI or XP Endo Finisher methods showed residual $Ca(OH)_2$ levels below 20%. The Chi-square test indicated a statistically significant difference ($p<0.001$) (Table 3).

When evaluating the efficacy of the irrigation activation methods based on isthmus location, it was observed that, in the apical isthmus, residual $Ca(OH)_2$ levels did not fall below 20% in any method except for the Er,Cr:YSGG group, which showed a 73.3% success rate. In the middle isthmus, 26.7% of acrylic models treated with the EDDY method, 13.3% with PUI, and 73.3% with the Er,Cr. YSGG method achieved residual $Ca(OH)_2$ levels below 20%. Both locations demonstrated statistically significant differences among the groups according to the Chi-square test ($p<0.001$) (Table 3).

Discussion

In the present in vitro study, the efficacy of five different irrigation activation techniques in removing $Ca(OH)_2$ from root canal isthmuses was evaluated using standardized 3D printed models. The investigation focused on two distinct anatomical levels—apical and middle isthmuses—representing regions where isthmus prevalence is reported to be highest. Previous studies using micro-computed tomography and stereomicroscopy have shown that isthmuses, particularly in the mesial roots of mandibular and maxillary first molars, most commonly occur within 3–5 mm from the apex, with both complete and incomplete forms frequently observed, especially in teeth with two canals (13,14).

The morphological characteristics of isthmuses, including their width and length, have been shown to significantly influence the effectiveness of irrigant activation. Robberecht et al. (15) demonstrated that short and wide isthmuses are more amenable to debridement, regardless of the activation technique employed. In the present study, the middle and apical isthmus regions were designed based on those morphological principles, with dimensions of 4 mm × 5 mm × 0.4 mm and 2 mm × 3 mm × 0.15 mm, respectively, to replicate clinically relevant anatomical variations.

This study's findings revealed that CNI was the least effective method overall, consistent with the existing literature (16,17). However, a noteworthy exception was observed in the middle isthmus region, where CNI demonstrated greater efficacy than the EDDY system—a result that diverges from previous reports. This discrepancy may stem from limitations inherent in the present methodology, particularly the use of two-dimensional digital image analysis (ImageJ) to assess residual $Ca(OH)_2$, which may have failed to capture the full volumetric extent of remnants in complex isthmus anatomies (18).

Previous studies have demonstrated that activation techniques such as XP Endo Finisher, PUI, and EDDY are significantly more effective than CNI in the removal of $Ca(OH)_2$ from root canal systems. Isthmus morphology and the duration of activation further modulate the effectiveness of these techniques; nonetheless, traditional needle irrigation remains consistently less effective across studies (19,20). EDDY, which utilizes a flexible polyamide tip driven by an air scaler, produces substantial hydrodynamic agitation, thereby enhancing irrigant flow and debris elimination, particularly in anatomically complex regions such as isthmuses (21). The XP Endo Finisher, owing to its adaptive alloy structure, can physically engage canal walls and disrupt $Ca(OH)_2$ residues even in highly irregular spaces. PUI employs ultrasonic energy to induce acoustic streaming and cavitation effects, thus facilitating deeper irrigant penetration and improved debridement efficacy (19). Certain studies suggest that EDDY and the XP Endo Finisher may outperform PUI in isthmus regions due to their superior adaptability to canal irregularities and more robust mechanical agitation (19,20). However, PUI continues to be regarded as a highly effective and widely adopted technique, and the differences in performance among these methods are not consistently found to be statistically significant (21). In the present in vitro study, no statistically significant difference was observed between the efficacy of PUI and XP Endo Finisher in $Ca(OH)_2$ removal, a finding that aligns with existing literature (22,23).

In the present study, irrigation activation using the Er,Cr:YSGG laser was found to be significantly more effective in the removal of $Ca(OH)_2$ from both the apical and middle isthmus regions, with statistically significant results. Notably, no $Ca(OH)_2$ residues were observed in any of the three acrylic models following laser activation. Previous studies employing standardized canal grooves to simulate isthmuses have reported that the Er,Cr:YSGG laser, particularly when used with a radial firing tip, achieves superior $Ca(OH)_2$ removal compared to other techniques. However, residual material was still detected across all experimental groups (24). Moreover, the existing literature consistently indicates that no activation method, including the Er,Cr:YSGG laser, is capable of achieving complete elimination of $Ca(OH)_2$ from all canal irregularities (25). In contrast to these findings, the present study demonstrated complete removal in the three acrylic models. This outcome is likely attributable to the injectable formulation of the $Ca(OH)_2$ employed and the relatively wide isthmus dimensions of the acrylic models used in the experimental setup.

Robberecht et al. (15) reported that laser activation was more effective than both EDDY and CNI methods in the removal of intracanal medicaments. Similarly, Swimberghe et al. (26) compared various activation techniques including EDDY, PUI, and laser, and found that laser activation demonstrated significantly superior efficacy. These findings support the acceptance of the first null hypothesis of the present study.

In this in vitro investigation, a higher amount of residual $Ca(OH)_2$ was observed in the middle isthmus region. Accordingly, the second null hypothesis was rejected. In contrast, Widbiller et al. (11) reported that greater debris accumulation tends to occur in the apical third of the root canal. It has been suggested that short and wide isthmuses are more amenable to effective cleaning than narrower ones, irrespective of the activation technique employed. Among the morphological parameters, isthmus width appears to be a more critical determinant of cleaning efficacy than length (11). The observed difference in this study is likely due to the relatively wider dimensions of the middle isthmus in the experimental models.

The present study has several limitations that should be acknowledged. First, dentinal surface cleanliness could not be assessed due to the methodological constraint of using a two-dimensional imaging system, which limited the evaluation to specific areas and excluded portions of the isthmus walls from analysis. As such, a comprehensive three-dimensional understanding of residual material distribution was not achieved. Second, the dimensional differences between the middle and apical isthmuses may have influenced the outcomes, particularly in terms of $Ca(OH)_2$ retention, and this morphological variability was not standardized across samples. Third, only an injectable form of $Ca(OH)_2$ was used in the experimental design. As a result, the findings cannot be generalized to other formulations such as hard-set or paste-based $Ca(OH)_2$, and the impact of material consistency on removability from isthmuses could not be assessed. These limitations should be considered when interpreting the results and their applicability to clinical scenarios.

Conclusion

Within the limitations of this in vitro study, the Er,Cr:YSGG laser-activated irrigation technique demonstrated superior efficacy in the removal of $Ca(OH)_2$ from root canal isthmus regions compared to other activation methods. The use of standardized 3D printed acrylic blocks with two distinct isthmus configurations enabled a controlled comparison free from anatomical variability. All activation techniques enhanced removal efficiency relative to CNI. These findings underscore the continued challenges associated with effective cleaning of anatomically complex areas and highlight the necessity of employing optimized irrigation protocols to address these difficulties.

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Use of AI for Writing Assistance: Not declared

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Conflict of Interest: None declared.

Ethical Approval: Not applicable.

Informed consent: Not applicable.

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ORIGINAL ARTICLE

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Effect of dual rinse® HEDP, propolis and EDTA on root dentin microhardness: An in vitro study

Birgül Özaşır, Tufan Özaşır, İzel Yeşil, Zeynep Serra Arslan, Kamran Gülşahı

Department of Endodontics, Baskent University Faculty of Dentistry, Ankara, Türkiye

Purpose: The aim of this in vitro study was to compare the effects of root canal irrigation agents—Dual Rinse HEDP, Propolis, and EDTA—on root dentin microhardness.

Methods: Forty human maxillary central incisors were sectioned buccolingually to yield 80 specimens. The samples were embedded in acrylic blocks; their surfaces were sanded and polished. Thereafter they were randomly assigned to four groups (n=20 each): Saline, EDTA, DR HEDP, and Propolis. Vickers microhardness measurements were performed before and after irrigation using a 100-gf load and a 10 s dwell time. Data were analyzed by one-way ANOVA followed by Student–Newman–Keuls multiple comparison test.

Results: All irrigation solutions except Saline produced a significant decrease in microhardness ($p<0.05$). The greatest percentage of hardness loss was observed in the Propolis group (24.24%), followed by DR HEDP (20.61%) and EDTA (19.56%). The Saline group showed no significant change (0.81%). No statistically significant differences were found among the EDTA, DR HEDP, and Propolis groups ($p>0.05$).

Conclusion: Although not statistically significant, Dual Rinse HEDP caused a greater decrease in root dentin microhardness than EDTA.

Keywords: Dentin microhardness; dual rinse HEDP; propolis; root canal irrigation; Vickers hardness test.

Introduction

The fundamental aim of root canal treatment is to eliminate microorganisms from the root canal system and to achieve a hermetic seal by combining mechanical instrumentation with chemical disinfection, a process known as chemomechanical preparation (1,2). Due to the complex morphology of the root canal system and the inaccessibility of certain areas to mechanical instrumentation, irrigation protocols play a crucial role in the success of endodontic treatment (3). During mechanical instrumentation, a smear layer composed of organic and inorganic components—including dentin debris, pulp tissue remnants, and bacteria—is formed on the root canal walls. This smear layer may hinder the penetration of irrigation solutions into the dentinal tubules, thereby compromising disinfection and the bonding ability of root canal sealers to the canal walls (4-6).

Sodium hypochlorite (NaOCl) is the most widely preferred root canal irrigating solution due to its strong antimicrobial activity and ability to dissolve organic tissues. However, its inability to effectively remove inorganic components necessitates the use of a chelating agent (7). A commonly adopted approach is final irrigation with ethyl-

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Correspondence: Birgül Özaşır. Department of Endodontics, Baskent University Faculty of Dentistry, Ankara, Türkiye

Tel: +90 312 – 246 66 15 e-mail: beren@baskent.edu.tr

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enediaminetetraacetic acid (EDTA). Nevertheless, EDTA has some disadvantages, including incomplete smear layer removal in the apical region, the requirement for sequential use with NaOCl due to chemical interactions that reduce the efficacy of available chlorine, and the potential for calcium ion loss and reduced dentin microhardness with prolonged use (8).

Certain irrigation solutions have been reported to alter the chemical structure of dentin, especially affecting the calcium/phosphorus (Ca:P) ratio (9). These alterations may negatively impact dentin permeability and solubility, ultimately reducing the adhesion quality of root canal filling materials. This could, in turn, lead to decreased sealer penetration and an increased risk of apical microleakage (10). To overcome the limitations associated with conventional chelators like EDTA, a "soft chelating agent" known as etidronic acid (1-hydroxyethane-1,1-diphosphonic acid; HEDP) has been proposed as an alternative (8). Dual Rinse® (DR HEDP; Medcem, Weinfelden, Switzerland), a commercially available powder formulation containing 9% HEDP, has been shown to maintain active chlorine levels for up to one hour when mixed with NaOCl (11). This formulation supports continuous chelation, preventing smear layer formation in areas where instruments contact the canal walls and debris accumulation in non-contact areas, thereby eliminating the need for sequential irrigation protocols (12). One of the irrigants evaluated in this study was propolis, a resinous substance naturally produced by bees. Rich in flavonoids, propolis contains a complex mixture of phenolic compounds, esters, terpenoids, beta-sterols, aromatic aldehydes, and alcohols. Its broad-spectrum biological properties, including antibacterial, antifungal, antiviral, anti-inflammatory, antioxidant, hepatoprotective, and immunomodulatory effects have been studied. Notably, propolis has shown promising efficacy against endodontic pathogens, even under challenging conditions such as the presence of smear layer, indicating its potential as an alternative to traditional irrigation solutions such as NaOCl. (13). Studies comparing propolis to NaOCl have shown that propolis possesses similar antibacterial activity and remains effective even in the presence of smear layer (14).

To our knowledge, no previous study has compared the effects of propolis and DR HEDP on root dentin microhardness. Therefore, this study aimed to evaluate and compare the effects of DR HEDP, propolis, and EDTA on root canal dentin microhardness as it may influence clinicians' irrigation preferences in practice. The null hypothesis was that the irrigation solutions would not significantly affect dentin microhardness.

Materials and Methods

This study followed the updated principles of the Declaration of Helsinki and was approved by the Non-Interventional Clinical Research Ethics Committee of Başkent University (Date: 25/06/2025, No: 25/153). It was also approved by the Medical and Health Sciences Research Board of Başkent University (Project No: D-DA25/08) and supported by the Başkent Research Fund.

Sample size determination

Power analysis was performed using G*Power 3.1 (Heinrich Heine University, Düsseldorf, Germany) based on the microhardness data reported by Dineshkumar et al. (15). A large effect size (f=0.40) was assumed, and it was determined that at least 19 samples per group were needed at a 0.05 error level and 80% power.

Tooth selection and sectioning

Forty extracted single-rooted human maxillary central incisors, extracted for orthodontic or periodontal reasons, were selected. Soft tissue remnants were cleaned using periodontal curettes, and the teeth were stored in distilled water until use. Digital radiographs were taken to verify the absence of calcifications and complex canal anatomy and to examine root curvature. Teeth with root curvature greater than 10° were excluded from the study. Crowns were removed at the cementoenamel junction under water cooling using a diamond disc, and roots were then split buccolingually. Each section was embedded horizontally in acrylic resin molds with the dentin surface exposed.

Preparation and Polishing

The exposed dentin surfaces were ground using a Presi Mecapol P230 grinder (Presi, Grenoble, France) with silicon carbide abrasive papers of P600, P800, and P1000, respectively, (Metkon Instruments Ltd., Bursa, Türkiye) under water cooling. Final polishing was done using felt discs and polishing paste (Preparations Diamantees Mecaprex, KMV, Grenoble, France).

Experimental Groups and Irrigation Protocols

In this study, saline, EDTA, DR HEDP, and propolis irrigants were used for microhardness measurement. The samples were randomly assigned to groups using a computer-generated randomization list created in Microsoft Excel. Each sample was given a unique number, and the RAND() function was used to assign them randomly to the experimental groups as follows:

Group 1: Saline (0.9% saline for 20 min - distilled water for 1 min)
Group 2: EDTA (20 min 2.5% NaOCl - 1 min distilled water- 1 min 17% EDTA - 1 min distilled water)
Group 3: DR HEDP (20 min DR HEDP - 1 min distilled water)
Group 4: Propolis (20 min 2.5% NaOCl - 1 min distilled water- 4 min 4% propolis - 1 min distilled water)

Preparation of irrigation solutions

Saline solution (Polifleks®, Polifarma Pharmaceutical Co., Türkiye) was used for Group 1 (control). For Groups 2 and 4, 2.5% NaOCl was prepared by mixing distilled water and 5% NaOCl (Microvem, Sakarya, Türkiye) at a 1:1 ratio. For Group 2, 17% ethylenediaminetetraacetic acid solution (AQUA-EDTA 17%, AQUA Medikal, Ankara, Türkiye) was used. For Group 3, 9% Dual Rinse® HEDP (Medcem, Weinfelden, Switzerland) solution was obtained by mixing 1 capsule (0.9 g) of etidronic acid powder with 10 mL of 2.5% NaOCl with a plastic spatula for 2 min, in accordance with the manufacturer's recommendations. For Group 4, 4% propolis solution was obtained by dissolving 500 mg tablet (Bee'O Up®, Bee&You Propolis Tablet, BEE'O, Istanbul, Türkiye) in 120 mL of warm distilled water. All solutions were prepared fresh and stored in the dark before the experiments. Each solution was applied in a volume of 5 mL to the dentin surfaces, and each group was rinsed with distilled water for 1 min between different solutions if the protocol requires.

Microhardness Test

All microhardness tests were conducted by a single operator blinded to the irrigation groups, while a second blinded operator recorded the pre- and post-irrigation microhardness measurements. Microhardness testing was conducted using a Vickers microhardness tester (HMV-700, Shimadzu Corp., Tokyo, Japan). A pyramidal tip was applied to the surface of each section for 10 seconds with a 100 gram-force (gf) load. The diagonals of the pyramidal scar formed on the section surface were measured under a stereomicroscope at x40 magnification. Representative microscopic images of the traces created by Vickers indentations in different regions of the root canal dentin are presented in Fig. 1. The diagonal lengths of these indentations were measured to calculate the Vickers hardness value (HV). For each sample, the average HV value obtained from three regions (coronal, middle, apical) was used. Pre-irrigation values were recorded, followed by irrigation procedures and post-irrigation measurements.

Statistical Analysis

Descriptive statistics were calculated as mean ± standard deviation, along with minimum and maximum values for each group. Kruskal–Wallis test was used to analyze the initial microhardness values, since they did not meet the assumption of normality. The Shapiro–Wilk test confirmed that both absolute and percentage change values were normally distributed ($p>0.05$), so these variables were analyzed using One-Way ANOVA, followed by Student–Newman–Keuls post-hoc test to determine pairwise differences. The significance level of $p<0.05$ was considered statistically significant. All analyses were performed using IBM SPSS Statistics for Windows, Version 25.0 (IBM Corp., Armonk, NY, USA).

Results

The effects of four different irrigation groups on dentin microhardness were evaluated using the Vickers microhardness test before and after the irrigation protocols. There was no statistical difference between initial microhardness values ($p>0.05$). Both the absolute and percentage changes were calculated for each group along with mean and standard deviation values. In terms of absolute change in microhardness compared to the initial values, a decrease of 1.62±5.83 was detected in the saline group, 11.01±5.57 in the EDTA group, 13.27±8.01 in the DR HEDP group and 13.38±5.83 in the Propolis group. When the percentage change was examined, a decrease of 0.81±15.30% was observed in the Saline group, 19.56±8.63% in the EDTA group, 20.61±10.99% in the DR HEDP group and 24.24±8.32% in the Propolis group, respectively. Table 1 shows the average microhardness values and the change

Table 1. Descriptive statistics of microhardness values before and after irrigation

	N	Initial HV Mean ± SD (Min-Max)	Final HV Mean ± SD (Min-Max)	ΔHV Mean ± SD	%ΔHV Mean ± SD
Saline	20	49.58±9.78 (25.80–60.80)	47.96±6.26 (36.40–55.60)	1.62±5.83*	0.81±15.30*
EDTA	20	55.51±8.11 (45.20–75.40)	44.50±7.19 (34.30–63.30)	11.01±5.57	19.56±8.63
DR HEDP	20	59.60±12.35 (37.50–82.30)	46.33±6.20 (37.80–62.70)	13.27±8.01	20.61±10.99
Propolis	20	53.77±8.00 (30.20–68.40)	40.39±5.53 (26.30–48.70)	13.38±5.83	24.24±8.32

N: number of samples; HV: Vickers Hardness Value; SD: standard deviation; Min: minimum; Max: maximum; ΔHV: Absolute change in microhardness; %ΔHV: Percentage change in microhardness. *Statistically significant difference ($p<0.05$, Student–Newman–Keuls test).

rates in microhardness before and after the irrigation protocols for each solution group. The decrease in microhardness compared to the initial value was significant in the groups except the Saline group ($p<0.001$). However, no statistically significant difference was found between the EDTA, DR HEDP and Propolis groups ($p>0.05$).

Discussion

In this study, the effects of 17% EDTA, which is frequently used in root canal irrigation, as well as DR HEDP and propolis, a natural product, on root dentin microhardness were evaluated. Present findings showed that all experimental groups, except the control (Saline), significantly reduced dentin microhardness, partially rejecting the null hypothesis.

The highest reduction was observed in the Propolis group, followed by DR HEDP and EDTA with no statistically significant differences. Dentin microhardness is clinically important for both the mechanical integrity of root canal walls and the bonding strength of root canal sealers. A decrease in microhardness may increase the brittleness of dentin, reducing the tooth's resistance to occlusal forces and compromising the prognosis. It may also reduce the adhesion of resin-based sealers (16,17). The Vickers microhardness test was chosen due to its precision in measuring small samples and sensitivity to physical changes caused by chemical agents (16). Consistent with previous studies (18,19), both pre- and post-irrigation microhardness values were recorded and compared with the control group.

To simulate clinical practice, all specimens were exposed to NaOCl. In the continuous chelation group, HEDP was mixed with NaOCl, whereas EDTA and propolis were applied after NaOCl in the sequential groups. All specimens were exposed to NaOCl for 20 min, approximating the duration of root canal instrumentation and tissue dissolution in clinical procedures. DR HEDP and EDTA produced similar reductions in microhardness. Literature findings vary, with some studies (2,20-23) reporting that DR HEDP causes less mineral loss than EDTA, while Grinkevičiūtė et al (24) observed greater microhardness loss with DR HEDP. The discrepancies may be due to differences in application time and methodology (22-25).

According to the present results DR HEDP caused a comparable decrease to EDTA, although used for a much longer time (20 min vs. 1 min). While HEDP is a weaker chelator compared to EDTA (2), its prolonged exposure may have compensated for this by gradually removing mineral content over time. The contact of chelating agents with dentin may lead to mineral loss through calcium and phosphate ion release, which can alter the structural and chemical integrity of dentin (20). In the present study, such chemical interactions may have contributed to the observed reduction in microhardness.

The different results of the effects of EDTA and DR HEDP groups on dentin microhardness between the present work and the study of Hazar et al. (2) may be due to the differences in the method used, irrigation time and measurement strategy. In this study, the average HV value was calculated by combining the microhardness measurements taken from the coronal, middle and apical regions of each sample and the analysis was performed on this single average value. In contrast, the study by Hazar et al. (2) evaluated each of the three root regions separately, and the region-specific effects were statistically analyzed. Furthermore, the application of EDTA was different in the present work (1 min instead of 2). These factors may underlie the differences in the findings.

This study's results showed that the Propolis group caused the highest decrease in dentin microhardness, although not at a statistically significant level. This result is consistent with the results of Elgendy et. Al (13). Unlike the present work, 4% propolis solution dissolved in dimethyl sulfoxide (DMSO) instead of distilled water caused a greater decrease in dentin microhardness than 17% EDTA. However, in the study by Bhagwat et al. (25), 4% propolis solution prepared with distilled water was found to be less effective on dentin microhardness than 17% EDTA. These contradictory findings may be related to formulation differences resulting from the natural structure of propolis. Ahangari et al. (14) reported that the composition of propolis varies significantly depending on factors such as source, extraction method (water-based or ethanol-based) and pH profile, which may directly affect the biological effects of propolis. In this context, it is difficult to make a direct generalization among the studies in the literature evaluating the effects of propolis on dentin microhardness. Therefore, the significant reduction observed in this study may have been shaped by the formulation, application time and solubility properties of propolis.

No study has been found in literature directly comparing HEDP and propolis in terms of dentin microhardness. Therefore, this study is the first to compare the structural effects of these two irrigants on dentin. This study demonstrates that EDTA, HEDP, and propolis may have similar negative effects on structural integrity when assessed in terms of dentin microhardness. Although HEDP and propolis formulations have been reported to be more protective on dentin microhardness in some studies (20-23), factors such as application method, duration and concentration can significantly affect the results (24).

This in vitro study has several limitations that should be acknowledged. Firstly, experimental conditions cannot replicate the complex biological environment of the oral cavity, particularly the influence of pulp tissue, physiological fluids, and intraoral temperature fluctuations. Secondly, although microhardness was assessed in three distinct regions (coronal, middle, and apical), the data were averaged for statistical analysis, potentially masking region-specific effects of the irrigation solutions. Moreover, the irrigation protocols and exposure times were standardized across groups for comparison but may not accurately reflect clinical practice where variability in application duration and technique exists. The chemical composition and concentration of propolis may also differ depending on its botanical source and extraction method, limiting the generalizability of the findings. Lastly, the sample size, though statistically powered, remains relatively small and may not capture the full biological variability of human dentin. Further in vitro and vivo studies that simulate clinical conditions are recommended to confirm these results and to explore strategies for minimizing adverse effects on dentin while maintaining adequate canal disinfection.

Conclusion

All tested irrigating solutions in this study reduced root dentin microhardness compared to the saline control, indicating that each can weaken the dentin structure. Among the experimental groups, the natural propolis irrigation solution produced the greatest reduction in dentin hardness, whereas the conventional chelator EDTA showed the mildest reduction; however, these differences were not statistically significant. In other words, continuous chelation with HEDP and the alternative herbal agent propolis were not inherently safer for dentin microhardness than EDTA, as all three agents exerted a similar negative impact on the structural integrity of dentin.

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ORIGINAL ARTICLE

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Effect of circadian rhythm on decayed, missing, filled teeth index and endodontic treatment

Elif Aslan,[1] Gozde Kotan,[2] Betul Aycan Uysal[1]

[1]Department of Endodontics, Health Science University Faculty of Dentistry, Istanbul, Türkiye
[2]Topcular Oral and Dental Health Center, Istanbul, Türkiye

Purpose: This study aimed to investigate the association between individuals' circadian typology and oral health status, as measured by the Decayed, Missing, and Filled Teeth (DMFT) index, as well as the prevalence of endodontic treatment.

Methods: Chronotypes were determined using the Morningness-Eveningness Questionnaire, which was administered through face-to-face interviews. The questionnaire comprised 26 items and was completed by 349 participants. In addition, each participant's oral health status was evaluated by recording their DMFT index and the presence of endodontically treated teeth through clinical examination and dental records. Statistical analyses of continuous variables, including means and standard deviations, were conducted using chi-square and analysis of variance tests. A p-value of <0.05 was considered to indicate statistical significance.

Results: No statistically significant differences were observed among the three chronotype groups (morning-, intermediate-, and evening-types) regarding the mean number of endodontically treated teeth (p>0.05). However, a significant difference in DMFT scores was found across the chronotype groups (p<0.05), with the lowest values observed in morning-types (4.14±1.952) and the highest in evening-types (5.48±2.686).

Conclusion: The results suggested that circadian rhythm may influence oral health status. Specifically, individuals with an evening-types appear to exhibit a greater predisposition to dental caries, which may increase their risk of requiring endodontic treatment if caries remain untreated.

Keywords: Circadian rhythm; DMFT index; endodontics.

Introduction

Circadian rhythm refers to the biochemical, physiological, and behavioural changes following a 24-hour cycle. The term "circadian" originates from the Latin words circa, meaning "approximately", and diem, meaning "a day" (1,2). Circadian rhythms are crucial in regulating a wide range of physiological processes, including the sleep-wake cycle, hunger and satiety, and the functions of various systems such as the endocrine, gastrointestinal, immune, respiratory, cardiovascular, and metabolic systems (3). This biological clock is governed by the suprachiasmatic nu-

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Correspondence: Betul Aycan Uysal. Department of Endodontics, Faculty of Hamidiye Dentistry, Health Science University, Istanbul, Türkiye

Tel: +90 507 – 239 95 07 e-mail: dr.betulaycanuysal@gmail.com

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cleus in the brain and is influenced by external cues such as light and darkness (4), which in turn affect melatonin secretion (5).

Melatonin is secreted by the pineal gland, the smallest endocrine gland in the human body (6). Being sensitive to light, melatonin reaches its peak secretion levels between 2:00 and 4:00 a.m. in humans. In adults, melatonin secretion typically begins between 9:00 and 10:00 p.m. and subsides between 7:00 and 9:00 a.m. (7). A decrease in melatonin levels is associated with a reduction in antioxidant activity, which results in increased production of reactive oxygen species (ROS) in saliva (8). Elevated levels of ROS in saliva contribute to the development of dental caries (9). Since melatonin is a circadian hormone, the relationship between circadian rhythm and the formation of dental caries is evident (4).

Dental caries is a prevalent and non-communicable condition that, according to the World Health Organization, affects approximately 2.3 billion individuals worldwide, corresponding to 32% of the global population (10). The pathogenesis of dental caries is primarily driven by the metabolic activity of cariogenic bacteria, which ferment dietary sugars and carbohydrates, leading to a decreased intraoral pH and subsequent demineralization of dental hard tissues over time (11,12).

Multiple studies suggest that poor sleep quality and insufficient sleep are linked to greater dental caries experience, as indicated by higher decayed–missing–filled teeth (DMFT) scores (13,14). Short sleep duration activates the sympathetic nervous system and compromises immune function, exacerbating the host's vulnerability to bacterial infections, including dental caries (15). Moreover, reduced salivary flow, commonly observed with sleep deprivation, diminishes the oral cavity's capacity to buffer acids and facilitate the remineralization of enamel (16,17). Conversely, excessive sleep duration may disrupt the circadian regulation of salivary secretion, potentially altering the composition of the oral microbiome and contributing to increased caries risk (18).

Chronotype refers to an individual's genetically influenced predisposition towards preferred sleep-wake patterns (19). Chronotypes are typically classified into three categories: Morning-, intermediate-, and evening-types. Morning-types tend to wake early and feel most alert during the early hours of the day, whereas evening-types prefer staying awake until late at night and often require an alarm to wake during the late morning or early afternoon. Intermediate-types exhibit no strong inclination towards either extreme, generally falling between them (20).

Individuals with an evening chronotype are more likely to exhibit irregular sleep schedules, which can contribute to a reduced salivary flow (21). Furthermore, evening-types are more prone to unhealthy lifestyle behaviours—such as missing breakfast, brushing their teeth less frequently, and late-night eating—which collectively contribute to poorer oral hygiene compared to morning-types (22,23).

The Decayed, Missing, and Filled Teeth (DMFT) index is calculated by quantifying the number of teeth in an individual's mouth that are decayed, missing due to caries, or filled due to previous carious lesions (24). Higher DMFT scores have been associated with poor sleeping reports due to the influence of inadequate sleep on immune system function, which can impair the body's ability to effectively combat cariogenic bacteria (13,14,25).

The null hypothesis of this study was that there is no significant difference in DMFT index and number of endodontically treated teeth among the individuals with different circadian rhythm. Therefore, the present study was aimed to investigate the association between individuals' circadian typology and oral and endodontic health status.

Materials and Methods

This cross-sectional study was conducted at the Bezmialem Vakif University between June and September 2021. The study was approved by the Ethics Committee of Bezmialem Vakif University (Date: 22/10/2019, No: 20/374) and conducted according to the Helsinki Declaration. A power analysis was conducted using the program package G*Power 3.1.2 (University of Duesseldorf, Duesseldorf, Germany), with an alpha level of 0.05 and a power of 0.80. The effect size was determined based on previous studies (2,23), and results indicated that a minimum of 208 respondents was required.

A total of 349 participants, aged 18 years or older, who were systemically healthy, aware of their sleep patterns, and knowledgeable about their oral treatments, completed a structured questionnaire comprising 26 items. The first seven questions collected demographic data (e.g., age, gender) and information related to the DMFT index, as well as the number of teeth that had undergone or required endodontic treatment.

The Morningness-Eveningness Questionnaire, originally developed by Horne and Östberg in 1976, was used to assess chronotype (26). This instrument comprises 19 Likert-type items designed to categorize individuals into morning-, intermediate-, or evening-type chronotypes. All questionnaires were administered via face-to-face interviews.

Clinical examinations were performed by an endodontist with 5 years of clinical experience to determine participants' DMFT scores and the number of teeth that had received or required endodontic treatment. The presence of endodontic treatment was assessed through intraoral clinical examination and radiographic evaluation.

Statistical Analysis

The data obtained were analyzed using SPSS version 22 (IBM, Armonk, NY, USA). Descriptive statistics (mean and standard deviation) were computed for continuous variables. Chi-square and analysis of variance (ANOVA) tests were used to assess statistical associations. For parameters showing significant differences in ANOVA, the Tukey HSD post hoc test was applied. A significance level of $p<0.05$ was considered statistically significant.

Results

On examining the distribution of participants across the chronotype groups, it was determined that the evening-type group comprised 117 (33.5%), the morning-type group 84 (24.1%), and the intermediate-type group 148 (42.4%) participants.

Statistical analysis revealed no significant differences in age across the three chronotype groups ($p=0.174$). The groups' age distributions, based on minimum and maximum values, were comparable, and the mean ages were also closely aligned across the groups. However, the morning-type group had a lower mean age than the other two groups (Table 1).

Statistical analysis revealed a significant difference in DMFT values between the three chronotype groups ($p=0.001$). The morning-type group exhibited the lowest DMFT score, while the evening-type group had the highest (Table 2).

No statistically significant differences were found in the average number of teeth with endodontic treatment between the three chronotype groups ($p=0.173$). The minimum and maximum values for the number of teeth with endodontic treatment were similar in all three groups, and the mean values were also closely aligned. However, the morning-type group had a lower average number of teeth with endodontic treatment than the other two groups (Table 3).

Table 1. Age distribution across chronotype groups (One-Way ANOVA)

Chronotype	N	Mean Age (Years)	Standard Deviation (SD)	Min Age	Max Age	p
Evening-type	117	33.03	11.951	18	63	0.174
Morning-type	84	29.99	10.801	19	64	
Intermediate-type	148	32.12	11.430	18	65	
Total	349	31.91	11.487	18	65	

($p<0.05$).

Table 2. Comparison of mean DMFT values across chronotype groups (One-Way ANOVA with Tukey HSD post hoc test)

Chronotype	N	Mean DMFT	Standard Deviation (SD)	Min DMFT	Max DMFT	p
Evening-type	117	5.48A	2.686	0	13	0.001
Morning-type	84	4.14B	1.952	1	10	
Intermediate-type	148	5.09C	2.393	0	13	
Total	349	4.99	2.448	0	13	

Groups labelled with different letters (A, B, C) differ significantly from each other according to Tukey HSD post hoc test ($p<0.05$).

Table 3. Comparison of mean number of endodontically treated teeth across chronotype groups (One-Way ANOVA)

Chronotype	N	Mean Number of Endodontically Treated Teeth	Standard Deviation (SD)	Min	Max	p
Evening-type	117	1.62	1.639	0	9	0.173
Morning-type	84	1.23	1.365	0	8	
Intermediate-type	148	1.53	1.445	0	7	
Total	349	1.48	1.498	0	9	

($p<0.05$)

Table 4. Comparison of gender distributions by chronotype (Chi-Square Test)

		Gender		χ2	p
		Female	Male		
Chronotype					
Evening-type	n (%)	58 (49.6%)	59 (50.4%)	0.635	0.728
Morning-type	n (%)	42 (50.0%)	42 (50.0%)		
Intermediate-type	n (%)	80 (54.1%)	68 (45.9%)		
Total	n (%)	180 (51.6%)	169 (48.4%)		

(p<0.05).

No statistically significant differences were found in the gender distribution between the three chronotype groups (p=0.728). No significant differences were observed in the distribution of male and female participants across the three groups (Table 4).

Discussion

It is well-established that individuals with different chronotypes exhibit varying levels of saliva production (21). Roestamadji et al. (27) noted that sleep deprivation increases cortisol secretion, leading to a decrease in saliva pH levels. In turn, this heightens susceptibility to dental caries. The present study focused the association between individuals' chronotypes and their dental-endodontic status and an increased risk of dental caries was observed in individuals with an evening chronotype. Notably, individuals in the morning chronotype group showed lower DMFT scores and fewer endodontically treated teeth, while the evening chronotype group exhibited higher values. Research has demonstrated that sleep deprivation places stress on the sympathetic nervous system, which alters the acidity and buffering capacity of saliva, presenting a risk factor for dental caries. These findings further emphasize the significant impact of sleep patterns on oral health (15).

Studies have shown a relationship between sleep deprivation of children and an increase in the number of S. mutans colonies in saliva (28-30). This finding suggests that sleep patterns may significantly impact children's oral health. An increased risk of dental caries in primary and permanent teeth was observed in Japanese children who stayed awake until late (29). The present study found that the morning chronotype group was associated with better oral health. In conclusion, the observation that sleep patterns play an important role in oral health, and that morning chronotypes may have better dental health, is consistent with the study by Arvidsson et al. (28).

In the present study, significant differences in DMFT values were found among the groups, with the evening chronotype group showing higher DMFT values than the morning and intermediate chronotype groups. This result suggested that the increased bacterial growth in the mouth overnight may elevate the risk of dental caries. The higher DMFT values in the evening chronotype group may reflect the effects of sleep deprivation and the increased bacterial colonization in the mouth during the night. In conclusion, the relationship between DMFT values and sleep patterns indicates that sleep deprivation may negatively affect oral health and increase the risk of dental caries. The null hypothesis was rejected.

Research by Sardana et al. (31) indicated that sleep deprivation weakens the immune system, increasing bacterial growth in the mouth, which could lead to caries formation. The lower DMFT values observed in the morning chronotype group in the present study supported the concept that regular sleep habits may help maintain oral health. Therefore, further research is required to better understand the relationship between sleep patterns and dental caries.

Based on the findings of Gaeta et al. (32), poor sleep quality is strongly associated with the development of apical periodontitis (AP), and insufficient sleep increases the risk of AP development. Similarly, it has been reported that the DMFT index is positively correlated with AP. These results suggested that sleep quality and DMFT values are important factors affecting oral health when considered together (32). In the present study, the lower DMFT values in the morning chronotype group suggest that sleep habits may directly impact oral health. Although no statistically significant difference was found between the chronotype groups regarding the number of teeth requiring endodontic treatment (p>0.05), this number was lower in the morning chronotype group. The similar distribution of individuals with endodontically treated teeth across the three groups may be explained by a tendency to prefer tooth extraction over root canal treatment due to various economic and social factors.

In our study, a statistically significant difference in DMFT indices was found between the chronotype groups, with the lowest value observed in the morning chronotype group and the highest in the evening chronotype group. However, no significant difference was found between the groups regarding the number of teeth requiring endodontic treatment. This finding may stem from the differences in the scope and clinical significance of the two parameters. The DMFT index is a comprehensive oral health indicator that includes decayed, missing, and filled teeth and provides a holistic view of an individual's overall dental health status. However, endodontic treatment represents a more limited clinical condition, typically involving severely decayed lesions that have affected the pulp. Therefore, while the prevalence of caries and treatment history may vary among individuals, this does not always result in the need for endodontic treatment. Additionally, the decision to perform endodontic treatment depends on not only clinical findings but also factors such as access to healthcare, treatment attitudes, physician preferences, and economic conditions. In this context, the notable differences observed in the DMFT index suggest that morning chronotype individuals may have more regular oral hygiene habits and preventive health behaviours. However, the fact that the need for endodontic treatment is less affected by these habits may have prevented the inter-group differences from becoming statistically significant.

A strength of the present study is that only systemically healthy individuals were included, which reduced potential confounding factors and increased the internal validity of the results. Systemic diseases such as diabetes mellitus, cardiovascular disorders, and immunosuppressive conditions have been shown to negatively affect oral health by elevating DMFT scores, increasing the risk of apical periodontitis, and compromising endodontic treatment outcomes (e.g., higher DMFT in diabetic patients, and lower RCT success in diabetics) (33–37). By excluding individuals with such conditions, the observed associations between chronotype and oral health parameters in this study are less likely to have been influenced by these systemic factors, thereby enhancing the study's internal validity.

This study has several limitations. It did not consider other significant factors that could affect oral health, such as dietary habits, smoking, and stress, which may have influenced the results. Another limitation is that the relationship between endodontic treatment and circadian rhythm was assessed solely based on the number of teeth requiring endodontic treatment or those that had already undergone treatment. Future studies could investigate the effects of circadian rhythm on AP.

Conclusion

Within the limitations of this study, it has been determined that circadian rhythm affects oral health. Individuals with an evening chronotype are more prone to dental caries. Therefore, it is recommended that these individuals pay more attention to their oral hygiene and undergo regular dental check-ups.

This study was presented at the "Genç Endodontistler Sempozyumu" in Zonguldak-2024 as an oral presentation by Elif Aslan.

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ORIGINAL ARTICLE

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Global and national prevalence of root canal dilacerations: A systematic review and meta-analysis

Elif Bahar Cakici,[1] Ersan Celik,[2] Mert Unal,[1] Seca Mutlu,[1] Fatih Cakici[1]

[1]Department of Endodontics, Ordu University Faculty of Dentistry, Ordu, Türkiye
[2]Department of Prosthodontics, Ordu University Faculty of Dentistry, Ordu, Türkiye

Purpose: This systematic review and meta-analysis aimed to determine the prevalence of root canal dilaceration in Türkiye and the world. Additionally, the difference in the prevalence of root dilaceration between Türkiye and the world population has also been examined.

Methods: This systematic review and meta-analysis was registered with the Open Science Framework (OSF) to ensure transparency and reproducibility of the research process (Registration DOI: https://doi.org/10.17605/OSF.IO/5UBKA). Our study was conducted following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) statements. The MeSH terms and keywords were used to search articles published in three electronic databases PubMed, Web of Science, and Scopus. The search strategy was limited to English and Turkish articles published before 12 December 2024. In addition, the bibliographic references of the qualifying papers were manually searched. Data were collected according to the inclusion and exclusion criteria. The included studies were assessed by two independent reviewers using the Joanna Briggs Institute's critical appraisal checklist for prevalence studies.

Results: Forty-four observational studies are included in this meta-analysis. 35435 patients and 103948 teeth were examined in these studies. The overall prevalence of root dilaceration was 9.1% (95% CI=0.065-0.125) in patients and 2.3 % (95% CI=0.016-0.035) in teeth. We found the prevalence of root dilaceration to be 5.2% (95% CI=0.029-0.09) in Türkiye. There was no statistically significant difference between the prevalence in Türkiye and the world when comparing studies that assessed the number of patients with dilaceration (P=0.0545). However, there was a statistically significant difference when comparing studies that focused on the number of dilacerations of teeth (P=0.03).

Conclusion: Within the limitations of this meta-analysis, root dilaceration was observed in 9.3% of individuals and 3.1% of teeth globally, with a lower prevalence (5.2%) identified in Türkiye. Due to the diagnostic and therapeutic challenges posed by such teeth, accurate diagnosis and well-structured treatment approaches are essential. Further research utilizing standardized diagnostic criteria and including diverse population samples is needed to clarify the underlying causes and enhance clinical management strategies.

Keywords: Prevalence; root dilaceration; root morphology.

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Correspondence: Mert Unal. Ordu University, Faculty of Dentistry, Department of Endodontics, Ordu, Türkiye
Tel: +90 553 – 979 15 98 e-mail: mert.unal.011@gmail.com

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Introduction

The term dilaceration was first defined in 1848 as a deviation or bending in the linear relationship between the crown and the root of a tooth (1). Throughout history, researchers have compared and described teeth with dilacerated roots using various shapes. For instance, Stewart (2) likened them to a police hand, while Moreau (3) described them as resembling a scorpion. The definition of root dilacerations varies in the literature (4,5). According to some authors, if there is an angle of 90 degrees or greater along the tooth or root axis, the tooth is considered to have mesial or distal dilaceration (4) however, another perspective defines dilaceration as a deviation of 20 degrees or more from the normal axis of the tooth at the apical portion of the root (6). The crowns of teeth with dilacerated roots are typically asymptomatic, and the diagnosis of these teeth can be made either through radiographic examination or during tooth extraction (6,7). There are certain limitations in detecting root canal dilaceration using two-dimensional radiographs. Periapical and panoramic radiographs provide information on mesiodistal curvature of the roots but do not offer insight into buccolingual curvature (7). In some cases, dental roots exhibit a ninety-degree curvature in the buccal or lingual direction, resulting in a characteristic "bull's-eye" or "target-like" appearance on radiographs, where a central round radiolucent area is surrounded by a radiopaque dentin border (8,9).

Various hypotheses have been proposed regarding the etiology of root dilaceration, with the leading hypothesis attributing its cause to mechanical trauma affecting primary teeth (10,11). Trauma occurring during the development of tooth roots negatively affects root development and leads to the formation of dilacerations in the roots. This hypothesis is challenged by recent literature in certain aspects, such as the inconsistency between childhood trauma and the incidence of dilacerations observed in tooth roots. The percentage of trauma experienced during childhood ranges from 11% to 30%, whereas the rate of dilaceration is significantly lower than this percentage (2,9,12). Another opposing view is that while traumas generally affect the anterior region, dilaceration is more commonly observed in the posterior teeth (4). The theory outside of trauma theory is the scar formation theory. In relation to primary teeth, developmental anomalies of the primary tooth germ, mechanical interaction during eruption, extraction of primary teeth, the effects of anatomical structures (maxillary sinus cortical bone, mandibular canal, or nasal fossa), pathological scar formation, cleft lip and palate, advanced root canal infections, ectopic development of the tooth germ, adjacent cysts, tumors, or odontogenic hamartomas, orotracheal intubation and laryngoscopy, tooth transplantation, and finally, hereditary factors have been identified in the scientific literature as factors contributing to the formation of root dilaceration (13–18). Some authors have reported in the literature that root dilacerations are associated with certain systemic diseases, such as Smith-Magenis syndrome (19), hypermobility type of Ehlers-Danlos syndrome (20), Axenfeld-Rieger syndrome (21), and congenital ichthyosis (22).

The access cavity during endodontic treatment should be prepared to provide as direct a pathway as possible to the apical foramen. The access cavity should be prepared in such a way that root canal instruments can be used comfortably without binding. The access cavity should be prepared in a shamrock shape to allow root canal instruments to easily reach the apex in a dilacerated root (23). After preparing the access cavity, the curvature and length of the canal should be assessed using scout files, and this information should be recorded for future sessions (23,24). Disposable files with passive tips should be preferred. During root canal shaping, clinicians should be cautious regarding complications such as canal blockage, apical transportation, apical perforation, and instrument fracture. If the lateral condensation technique is chosen for root canal obturation, it should be ensured that the spreader reaches 1 mm shorter than the working length, and the spreader used during the filling process should be made of a flexible metal that will not fracture. Some studies suggest that heat-based filling techniques are more successful in achieving an apical seal, while other studies oppose this view (23).

Despite numerous studies and reviews on the prevalence of dental root dilacerations in the population, to the best of our knowledge, there is no systematic review or meta-analysis in the current literature on this topic. The aim of this systematic review and meta-analysis is to determine the prevalence of dental root dilacerations in the population. Additionally, it seeks to test whether there is a significant difference in the prevalence of dilaceration between our country and the world population.

Materials and Methods

This systematic review and meta-analysis adhered to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines (25) and was registered on the Open Science Framework (OSF) to promote transparency and reproducibility (Registration DOI: https://doi.org/10.17605/OSF.IO/5UBKA).

In our study, the population, outcome, and study design questions are as follows:

Population: Individuals with permanent teeth.

Outcome: Individuals and teeth with root dilaceration (root curvature).

Study design: Observational studies.

Inclusion criteria

Studies published before December 12, 2024, either as early or fully published in Turkish or English, were included. Among the studies retrieved from the searches, those that directly reported the prevalence of root dilaceration or could provide it through calculations were included.

Exclusion criteria

Case reports, theses, and conference proceedings related to the prevalence of root dilaceration were also excluded. Studies that did not provide clear results on the prevalence of root dilaceration and those where attempts to contact the corresponding authors for data retrieval were unsuccessful were excluded.

Databases and review strategies

Three databases commonly used for health-related publications (PubMed, Web of Science, and Scopus) were systematically searched by two independent authors (U.M., M.S.) up to December 12, 2024. The electronic search strategy was developed by combining the most frequently cited descriptors in previous publications on this topic, using both Medical Subject Heading (MeSH) terms and free-text keywords. The following terms were combined for the database search: "Permanent teeth," "Permanent tooth," "Root dilaceration," and "Prevalence." The Boolean operators "AND" and "OR" were applied to combine the terms. Additionally, manual searches were conducted for references of the included articles and previous reviews. To control for potential bias, two researchers carried out all processes independently (U.M., M.S.).

Study selection and data collection

The search results obtained from the databases mentioned above were imported into a reference management program (EndNote, Clarivate Analytics, Pennsylvania, USA). Duplicate publications were removed using this program. The remaining studies were transferred to Microsoft Excel, and any duplicate entries were manually excluded. The relevant studies were then selected based on the research criteria by reviewing the title, abstract, and full text in sequence. Full-text articles selected by two independent researchers were compiled into a single file. Disagreements between the researchers were resolved through discussions, and for studies where consensus could not be reached, the opinion of an experienced researcher (C.F.) was sought.

Data such as author, country, year, sample size, prevalence, method, study design, associated diseases, inter-observer evaluation, and diagnostic methods were extracted from the selected studies.

Methodological quality assessment of the studies

The methodological quality assessment of the studies included in this systematic review and meta-analysis was performed using the checklist for prevalence studies developed by the Joanna Briggs Institute (JBI) (26).

This checklist contains nine questions, and each question is evaluated by responding with "yes," "no," "unclear," or "not applicable." If fewer than four questions were answered with "yes," the methodological quality level was considered low; if five to six questions were answered with "yes," the methodological quality level was considered moderate; and if seven to nine questions were answered with "yes," the methodological quality level was considered high. No individual studies were excluded based on methodological quality. These procedures were conducted independently by two researchers. In case of disagreements, a final decision was made through discussion or by consulting a more experienced researcher.

Data Synthesis

To conduct this systematic review and meta-analysis, Comprehensive Meta-Analysis 3 (CMA) - Free Trial version was used. Heterogeneity among studies was analyzed using the Cochran Q and Higgins I^2 tests. If $I^2 \leq 50\%$, a fixed-effects model was applied; otherwise, a random-effects model was used (27). The statistical analysis was conducted using the number of cases reported in the included studies, and the pooled prevalence estimates were calculated and presented in the forest plots as event rates (proportions) with corresponding 95% confidence intervals. Additionally, meta-regression was performed to test if there was a difference in prevalence between our country and the global population. All tests were two-tailed, and a p-value of less than 0.05 was considered statistically significant. Bias assessment in the meta-analysis was tested using the Egger Regression method (28).

Results

Study selection and data collection

A total of 278 studies were identified from three databases using MeSH terms (Table 1). Twenty-eight duplicate studies were identified and removed using EndNote and manual screening. Two independent authors (U.M., M.S.) reviewed the titles of the remaining 250 studies and excluded 101 irrelevant studies. The abstracts of the remaining 149 studies were then screened, and an additional 101 irrelevant studies were excluded. Consequently, 48 full-

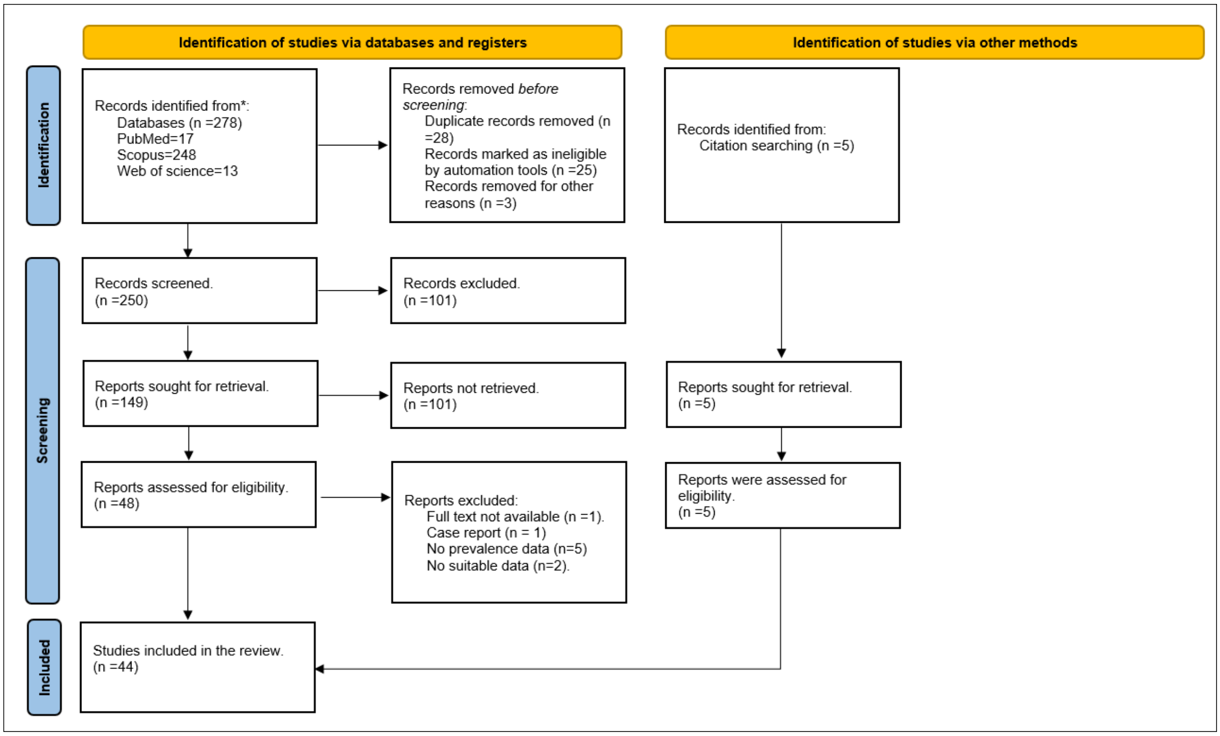

Fig. 1. Flow diagram of literature search and selection criteria (adapted from the PRISMA 2020 flowchart).

text articles were retained for further evaluation.

Of the 48 studies assessed in the full-text review, nine were excluded for the following reasons: Five studies (29–33) lacked prevalence data, one study (20) was a case report, and another study (7) was excluded due to the unavailability of the full text as it had been removed from the database. In addition, one study (34) contained data unsuitable for meta-analysis, and despite attempts to contact the authors for clarification, no response was received. Another study (35) was excluded because the data on root dilaceration were reported subjectively by observers rather than providing definitive quantitative values.

Table 1. Search results by databases

Pubmed database search results			
1	P	Permanent teeth OR permanent tooth Filters: English	30.943
2	O	Root dilaceration Filters: English	303
3	SD	Prevalence Filters: English	3,900.861
4	Totally	1 AND 2 AND 3 Filters: English	17
Scopus database search results			
1	P	Permanent teeth OR permanent tooth Filters: English	3,878,777
2	O	Root dilaceration Filters: English	423
3	SD	Prevalence Filters: English	86,662
4	Totally	1 AND 2 AND 3 Filters: English	248
Web of science database search results			
1	P	Permanent teeth OR permanent tooth Filters: English	15,783
2	O	Root dilaceration Filters: English	118
3	SD	Prevalence Filters: English	1,147,861
4	Totally	1 AND 2 AND 3 Filters: English	13

P: Population, O: Outcome, SD: Study Design.

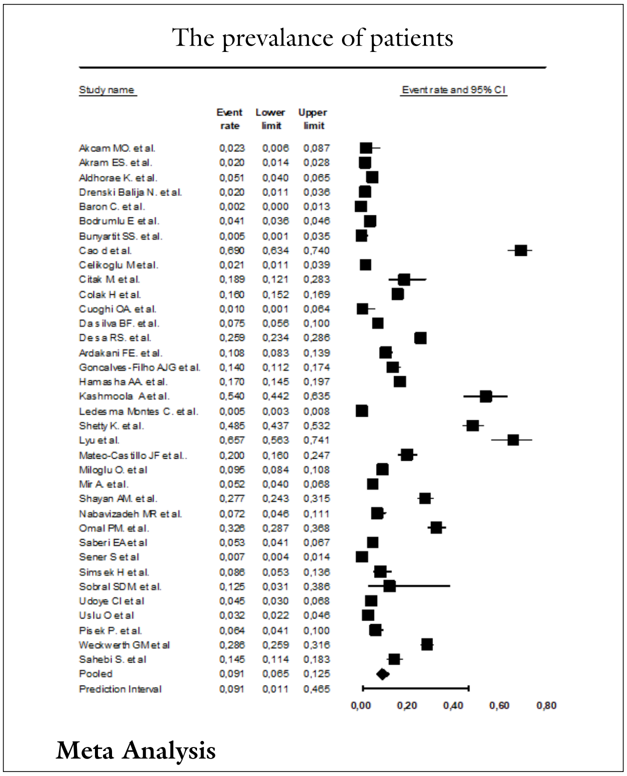

Fig. 2. Forest plot showing the prevalence of patients with root dilaceration.

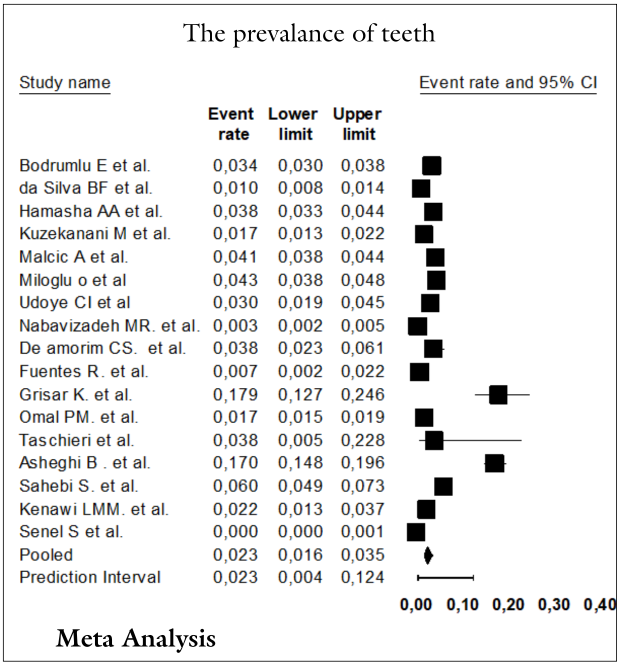

Fig. 3. Forest plot showing the prevalence of teeth with root dilaceration.

Following the screening process, thirty-nine studies remained. Additionally, five studies were added because of manual searching of references of selected studies and reviews, resulting in a total of 44 articles for analysis (Appendix 1; Fig. 1). Thirty-six studies (4,36–70) were analyzed using patient data and seventeen studies (4,5,41,55,57,58,61,64,67,70–77) were analyzed using teeth data. The data from nine studies (4,41,55,57,58,61,64,67,70) were based on both the number of patients and the number of teeth.

Characteristics of Included Studies

Our analysis was conducted with study results from nineteen countries across five continents. There were nine studies from Türkiye (36,41,44–46,55,61,65,68). A total of 35435 patients and 103948 teeth were examined in these studies. Six studies (43,53,70,73,74,77) utilized CBCT as the method, while one study (76) used both CBCT and two-dimensional radiography, and the remaining studies employed two-dimensional radiography. In fourteen studies (36,38,42,43,45,47,54,59,65,68–70,72,77) compared observers. The included studies generally involved populations with cleft lip and palate (36,59,69), Down's syndrome (47), tooth agenesis (44,45), obesity (65), impacted teeth (43,53,73), Kabuki's syndrome (66) and orthodontic patients (68). Retrospective methodology was predominantly chosen as the study design.

Meta-Analysis Results

The meta-analysis was conducted based on two types of data. The first type included studies that were based on the number of affected individuals in studies. A total of 36 studies were included in this analysis. The results of this analysis were determined as I^2=98.76 and Tau=1.050. Since I^2>50, a random-effects model was selected. The mean effect size was found to be 0.091, with a confidence interval of 0.065–0.125 (Fig. 2).

Based on the affected teeth, a total of 17 studies were included in the analysis. The results of this analysis were found to be I^2=98.566 and Tau=0.807. Since I^2>50, a random-effects model was selected. The mean effect size was determined as 0.023, with a confidence interval of 0.016–0.035 (Fig. 3).

Of the nine studies conducted in Türkiye (36,41,44–46,55,61,65,68), all studies reported data based on patient prevalence, while only three studies reported tooth prevalence. The analysis of the nine studies based on patient prevalence was I^2=98.61, Tau=0.873. Since I^2>50, a random-effects model was selected. The mean effect size was 0.052 with a confidence interval of 0.029–0.090 (Fig. 4). Three studies (41,55,61) have been carried out on the

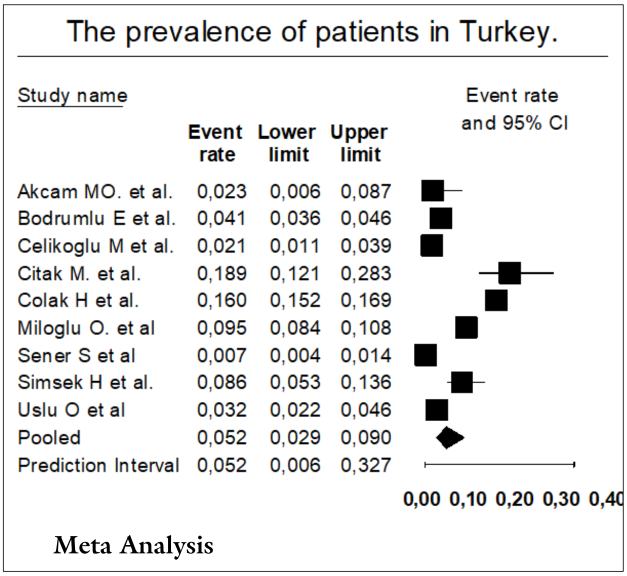

Fig. 4. Forest plot showing the prevalence of root dilaceration in Türkiye based on the number of patients.

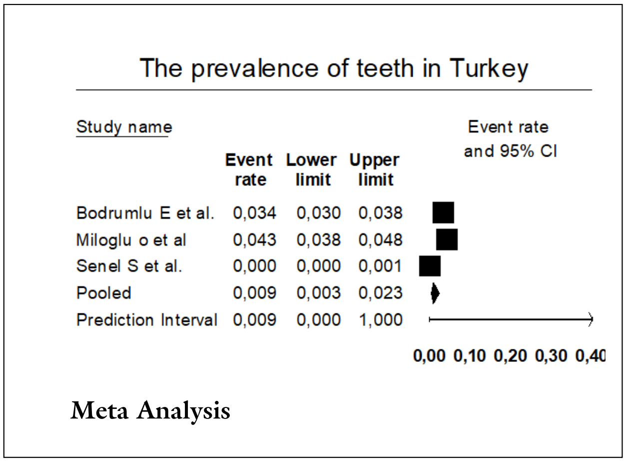

Fig. 5. Forest plot showing the prevalence of root dilaceration in Türkiye based on the number of teeth.

prevalence of teeth with root dilaceration in Türkiye. The analysis of these studies was I2=99.136, Tau=0.879, mean effect size 0.009 with a confidence interval of 0.003–0.023 (Fig. 5).

To compare the prevalence of root dilaceration between Türkiye and the global average, a meta-regression analysis was conducted. Although the prevalence of root dilaceration in Türkiye (0.052, 95% CI: 0.029-0.090) was lower than the global prevalence (0.091, 95% CI: 0.065-0.125), this difference was not statistically significant (P=0.0545) (Fig. 6). However, when comparing studies evaluating the prevalence of teeth, there was statistically significant difference between the dilaceration of Türkiye and the global

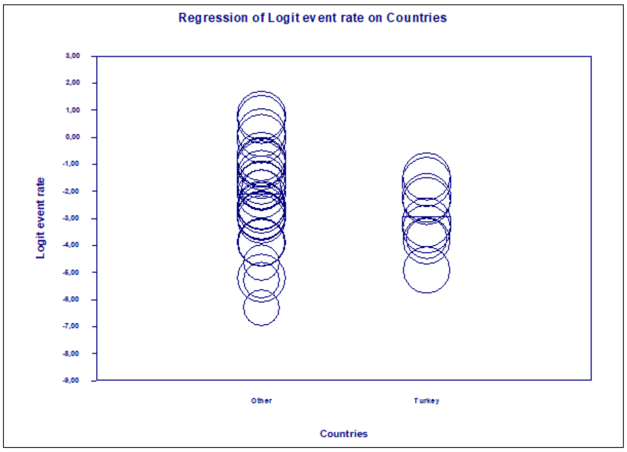

Fig. 6. Meta-Regression Between Türkiye and Other Countries (prevalence of patient).

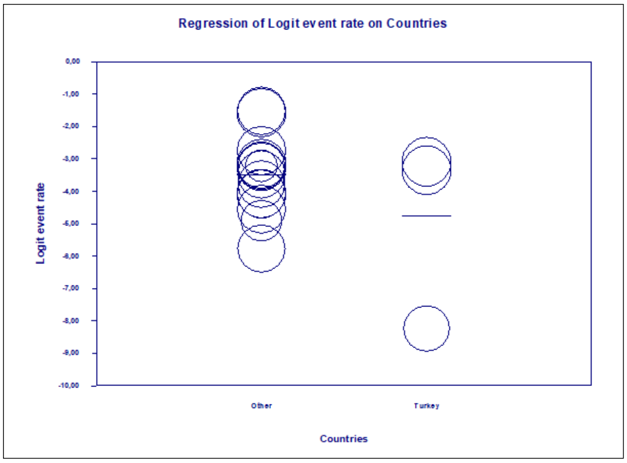

Fig. 7. Meta-Regression Between Türkiye and Other Countries (prevalence of teeth).

prevalence (P=0.03) (Fig. 7). Among the countries evaluated, the lowest prevalence of root dilaceration was observed in France (0.2%, 95% CI=0.000–0.013), whereas the highest prevalence was reported in China (68.1%, 95% CI=0.633–0.725).

Methodological quality assessment of the studies

In our meta-analysis, the presence of publication bias was tested using the Egger Regression Method. According to this analysis, the p-value was found to be 0.13 for studies based on affected individuals and 0.76 for studies based on affected teeth. Therefore, no publication bias was detected in these comparisons.

To assess publication bias in individual studies, the Joanna Briggs Institute (JBI) critical appraisal checklist for prevalence studies was used. In our analysis, 44 studies were included (Appendix 2). Among these: 8 Studies (37,48,53,56,61,64,71,76) answered "yes" to only one question, 7 studies (39,51,54,68,69,72,73) answered "yes" to only two questions, 15 studies (4,5,40,41,44,46,49,50,55,60,62,66,67,74,75) answered "yes" to three questions, 11 studies (36,38,43,45,47,52,57,58,63,70,77) answered "yes" to four questions. These studies were categorized as low methodological quality evidence.

Two studies (59,65) answered "yes" to six questions. These studies provided moderate methodological quality evidence. One study (42) answered "yes" to seven questions. This study provided high methodological quality evidence. Twenty-nine studies had a sample framework appropriate for the target population. Five studies (42,52,57,58,63) had participants appropriately sampled. Four studies (42,43,59,65) met the sample size sufficiency criteria. Twenty-nine studies fully described the study subjects and the geographic region where prevalence was determined. Three studies (42,43,65) adequately covered the defined sample in their data analysis. All studies used valid methods for case identification. Thirteen studies measured the condition reliably and consistently across all participants. Two studies (51,59) conducted appropriate statistical analysis. None of the studies met the response rate sufficiency criterion.

Discussion

Our study utilized the three most preferred databases for publishing dentistry-related studies (PubMed, Scopus, Web of Science). A total of 278 publications were screened from these databases, and an additional five studies were identified through manual search. In meta-analysis studies, it is recommended that searches cover all relevant databases without language restrictions. However, a limitation of our study is that the search was conducted in only three databases and included publications in English and Turkish. The included studies were conducted among dental patients, which prevents our findings from providing definitive evidence regarding the root morphology of an entire population or ethnicity. For conclusive evidence, data should be collected from all individuals within a population. Therefore, our analysis is based solely on data obtained from dental patients and does not fully represent the general population. Another limitation of our study is that the included studies do not cover all ethnicities worldwide and do not exhibit an evenly distributed representation. While some countries contributed multiple studies, others had no research available on this topic. These factors define the limitations of our study. Despite these constraints, our meta-analysis included 44 studies from 19 countries across five continents.

There are differences in the methods used to detect root dilacerations in the included studies. While seven studies utilized cone-beam computed tomography (CBCT) with three-dimensional imaging for detection, thirty-eight studies employed orthopantomography and periapical radiographs. Since three-dimensional radiographic techniques allow for the evaluation of tooth roots in three dimensions, they may provide more accurate and precise results. However, there is no definitive evidence regarding the superiority of one method over the other in detecting root dilacerations. Therefore, future studies should focus on evaluating the accuracy and reliability of different diagnostic methods for detecting root dilacerations.

Among the included studies, twenty-seven studies assessed root dilaceration based on patients rather than the number of affected teeth. Eight studies, on the other hand, reported their findings based solely on the number of affected teeth without considering the number of patients. Additionally, nine studies provided information on both the number of affected teeth and the number of affected individuals. Future studies should report both the localization and number of affected teeth, as well as the proportion of affected individuals, to facilitate more precise analyses and improve the accuracy of future meta-analyses.

In the analyzed studies, the most frequently referenced diagnostic approach for identifying root dilacerations was that described by Hamasha et al. (4). However, upon closer examination, it became evident that Hamasha et al. (4) did not introduce a novel diagnostic method but rather adopted the well-established technique developed by White and Pharoah (9). According to this approach, a tooth was considered to present with dilaceration when the angle formed between the long axis of the tooth and the deviated portion of the root exceeded 20°. This threshold has been widely utilized in the literature due to its reproducibility and clinical applicability. Deviations of 90° or greater along the tooth or root axis were classified as indicators of severe dilaceration, particularly in the mesial or distal directions (4).

A few studies (64,70,77) employed alternative diagnostic methods derived from four different studies (6,78–80), which demonstrated variations in angle thresholds and in the classification of curvature severity (mild, moderate, severe). Some researchers adopted Schneider's method, originally developed for assessing root canal curvature, while others utilized digital measurement tools such as AutoCAD or specialized imaging software, offering greater precision and reproducibility compared with manual protractor-based technique. In addition to diagnostic variability, differences in dilaceration prevalence were observed depending on tooth type. Maxillary central incisors were the most frequently affected teeth, a finding often associated with trauma to their primary predecessors (12). Posterior teeth demonstrated lower prevalence but were also affected in specific patient populations, such as those with craniofacial anomalies including cleft lip and palate (36,47,59,66,69). From a clinical perspective, these findings emphasize the importance of thorough radiographic evaluation, particularly in patients with a history of dental trauma, craniofacial developmental disorders, or orthodontic treatment needs. Maxillary incisors and multi-rooted posterior teeth, which are more susceptible to dilaceration, may present significant challenges during endodontic and orthodontic procedures; therefore, clinicians are advised to exercise particular caution when managing these tooth types.

The methodological quality of the included studies, except for three, was observed to provide low-quality evidence. This finding highlights the lack of utilization of available checklists in these studies. To achieve higher methodological quality, it is recommended that existing checklists for observational studies available in the current literature be employed.

Although numerous reviews on root dilacerations exist, no meta-analysis has previously been conducted on this topic. The comparison of the prevalence of dilaceration in our country with the global prevalence, as well as its association with syndromes and diseases, represent a strengths of our study. Furthermore, the calculation of both patient-based and tooth-based prevalence provided more detailed findings, and the observed difference between these two prevalence rates (with tooth-based prevalence being lower) demonstrated that not every tooth is affected when dilaceration is present. In the patient-based analysis, no statistically significant difference was observed between Türkiye and the global average in terms of root dilaceration prevalence. However, in the tooth-based analysis, the prevalence of root dilaceration in Türkiye was found to be lower than the global average. To clarify the reasons for this discrepancy, future studies comparing different countries within the same patient populations are warranted.

Conclusion

Root dilaceration was detected in 9.3% of individuals and 3.1% of teeth globally, with a lower prevalence observed in Türkiye (5.2%). Considering the diagnostic and therapeutic challenges posed by such teeth, clinicians should ensure accurate diagnosis and adopt carefully planned treatment strategies. Future research with standardized diagnostic criteria and diverse population samples is warranted to better understand the etiological factors and to improve clinical management approaches for root dilacerations.

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Appendix 1. The characteristic features of the studies

Author Name	Country	Year	Sample Size	Prevalence	Method	Study Design	Associated Diseases	Inter-Observer Assessment	Diagnostic Methods
Akcam et al. (36)	Türkiye	2010	87 P	2 P	OPG	Retrospective study	Cleft lip and palate	+	Hamasha et al. (4) (Sharp curve of 90 degrees or more)
Akram et al. (37)	Pakistan	2019	1500 P	30 P	Radiographic examinations	Retrospective study	Dental developmental alterations	-	-
Aldhorae et al. (38)	Yemen	2019	1202 P	61 P	OPG	Retrospective study	-	+	-
Ardakani et al. (39)	Iran	2007	480 P	72 P	OPG	Retrospective study	Dental developmental alterations	-	White et al. (9) (90° or more from the normal long axis of the tooth)
Asheghi et al. (77)	Iran	2023	927 T	158 T	CBCT	Retrospective study	-	+	Chohayeb et al. (6) Santana et al. (78) (20 degrees on the root surface)
Baron et al. (40)	France	2018	551 P	1 P	OPG	Retrospective study	-	-	-
Bodrumlu et al. (41)	Türkiye	2013	5504 P 9406 T	225 P 323 T	OPG	Retrospective study	-	-	White et al. (9) (90° or more from the normal long axis of the tooth)
Bunyarit et al. (42)	Bangladesh	2017	200 P	1 P	OPG	Retrospective study	Gender Dimorphism	+	-
Cao et al. (43)	China	2021	290 P	200 P	CBCT	Retrospective study	İmpacted canines	+	-

Celikoglu et al. (44)	Türkiye	2011	374 P Study Group 98 P Control Group	7 P Study Group 3 P Control Group	OPG	Retrospective study	Third molar agenesis	-	Hamasha et al. (4) (Sharp curve of 90 degrees or more)
Citak et al. (45)	Türkiye	2016	90 P	17 P	OPG	Retrospective study	Maxillary lateral incisor agenesis	+	Hamasha et al. (4) (Sharp curve of 90 degrees or more)
Colak et al. (46)	Türkiye	2012	6912 P	1108 P	OPG	Retrospective study	-	-	Hamasha et al. (4) (Sharp curve of 90 degrees or more)
Cuoghi et al. (47)	Brazil	2016	105 P	1 P	OPG	Retrospective study	Down's Syndrome	+	-
Da Silva et al. (64)	Brazil	2012	548 P 3948 T	41 P 41 T	OPG	Retrospective study	-	-	Schneider (79) Santana et al. (78) Erlich et al. (80) (The deviations greater than 20°)
de Amorim et al. (71)	Brazil	2018	423 T	16 T	PR	Retrospective study	Dental trauma	-	Hamasha et al. (4) (Sharp curve of 90 degrees or more)
de Sá et al. (48)	Brazil	2021	1111 P	288 P	OPG	Retrospective study	Dental developmental alterations	-	-
Drenski et al. (49)	Croatia	2022	506 P	9 T	OPG	Retrospective study	-	-	-

Fuentes et al. (72)	China	2017	412 T	3 T	OPG	Cross-sectional descriptive study	-	+	Hamasha et al. (4) (Sharp curve of 90 degrees or more)
Goncalves-Filho et al. (50)	Brazil	2014	478 P	67 P	OPG	Retrospective study	-	-	-
Grisar et al. (73)	Belgium	2018	162 T	29 T	CBCT	Retrospective study	İmpacted canines	-	-
Hamasha et al. (4)	Jordan	2002	814 P 4655 T	138 P 176 T	OPG	Retrospective study	-	-	White et al. (9) (90° or more from the normal long axis of the tooth)
Kashmoola et al. (51)	Malaysia	2021	100 P	54 P	OPG	Cross-sectional study	-	-	-
Kenawi et al. (74)	Saudi Arabia	2022	630 T	14 T	CBCT	Retrospective study	-	-	-
Kuzekanani et al. (75)	Iran	2019	3150 T	52 T	OPG	Retrospective study	-	-	Hamasha et al. (4) White et al. (9) (Sharp curve of 90 degrees or more)
Ledesma-Montes et al. (52)	Mexico	2016	3522 P	19 P	OPG	Retrospective study	-	-	-
Lyu et al. (53)	China	2018	108 P	71 P	CBCT	Retrospective study	Impacted central incisors	-	-
Malčić et al. (5)	Croatia	2006	15073 T	616 T	OPG PR	Retrospective study	-	-	Hamasha et al. (4) (Sharp curve of 90 degrees or more)

Mateo-Castillo et al. (54)	Brazil	2019	330 P	66 P	OPG	Retrospective study	Non-syndromic Pierre Robin Non-syndromic Cleft palate	+	-
Miloglu et al. (55)	Türkiye	2010	2251 P 6386 T	214 P 276 T	OPG	Retrospective study	-	-	Hamasha et al. (4) (Sharp curve of 90 degrees or more)
Mir et al. (56)	India	2018	1000 P	52 P	OPG PR	Radiographic study	-	-	-
Nabavizadeh et al. (57)	Iran	2013	6146 T 250 P	19 T 18 P	PR	Retrospective study	-	-	Hamasha et al. (4) (Sharp curve of 90 degrees or more)
Omal et al. (58)	India	2012	506 P 16192 T	165 P 269 T	OPG	Retrospective study	-	-	-
Pisek et al. (59)	Thailand	2013	280 P	18 P	OPG	Cross-sectional study	Cleft lip	+	-
Saberi et al. (60)	Iran	2016	1172 P	62 P	OPG	Retrospective study	-	-	-
Sahebi et al. (70)	Iran	2023	400 P 1537 T	58 P 92 T	CBCT	Retrospective study	-	+	Chohayeb et al. (6) Santana et al. (78) (Curvature of greater than 20 degrees from the longitudinal axis of the tooth)
Sener et al. (61)	Türkiye	2011	34169 T 1100 P	9 T 8 P	OPG	Retrospective study	-	-	-
Shayan et al. (62)	Iran	2022	602 P	167 P	OPG	Retrospective study	-	-	-
Shetty et al. (63)	The United Arab Emirates	2017	425 P	206 P	OPG	Retrospective study	-	-	-

Simsek et al. (65)	Türkiye	2019	186 P	16 P	OPG	Retrospective study	Obesity	+	-
Sobral et al. (66)	Brazil	2013	16 P	2 P	PR	Retrospective study	Kabuki syndrome	-	-
Taschieri et al. (76)	Italy	2012	26 T	1 T	PR CBCT	Retrospective study	Endodontic surgery	-	White et al. (9) (90° or more from the normal long axis of the tooth)
Udoye et al. (67)	Nigeria	2009	465 P 706 T	21 P 21 T	PR	Retrospective study	-	-	Hamasha et al. (4) (Sharp curve of 90 degrees or more)
Uslu et al. (68)	Türkiye	2009	900 P	29 P	OPG PR	Retrospective study	Orthodontic patients	+	Hamasha et al. (4) (Sharp curve of 90 degrees or more)
Weckwerth et al. (69)	Brazil	2016	974 P	279 P	OPG	Retrospective study	Nonsyndromic cleft lip and/or palate	+	Hamasha et al. (4) (Sharp curve of 90 degrees or more)

P: Patient, T: Teeth, OPG: Orthopantomography, PR: Periapical radiography, CBCT: Cone-beam computed tomography

Appendix 2. Methodological quality assessment

Author Name	Was the sample framework appropriate to address the target population?	Were the study participants appropriately sampled?	Was the sample size adequate?	Were the study topics clearly defined?	Was the data analysis conducted in a way that sufficiently covered the defined sample?	Were valid methods used to identify the condition?	Was the condition measured in a standard and reliable manner for all participants?	Was an appropriate statistical analysis conducted?	Was the response rate sufficient, and if not, was the low response rate properly addressed?	Methodological quality
Akcam et al. (36)	Y	N	U	Y	N	Y	Y	N	NA	LOW (4)
Akram et al. (37)	N	N	U	N	U	Y	N	N	NA	LOW (1)
Aldhorae et al. (38)	Y	N	U	Y	U	Y	Y	N	NA	LOW (4)
Ardakani et al. (39)	Y	N	U	N	U	Y	N	N	NA	LOW (2)
Asheghi et al. (77)	Y	N	U	Y	U	Y	Y	N	NA	LOW (4)
Baron et al. (40)	Y	N	U	Y	U	Y	N	N	NA	LOW (3)
Bodrumlu et al. (41)	Y	N	U	Y	U	Y	N	N	NA	LOW (3)
Bunyarit et al. (42)	Y	Y	Y	Y	Y	Y	Y	N	NA	HIGH (7)
Cao et al. (43)	N	N	Y	N	Y	Y	Y	N	NA	LOW (4)
Celikoglu et al. (44)	Y	N	U	Y	U	Y	N	N	NA	LOW (3)
Citak et al. (45)	Y	N	U	Y	U	Y	Y	N	NA	LOW (4)
Colak et al. (46)	Y	N	U	Y	U	Y	N	N	NA	LOW (3)
Cuoghi et al. (47)	Y	N	U	Y	U	Y	Y	N	NA	LOW (4)
da Silva et al. (64)	N	N	U	N	U	Y	N	N	NA	LOW (1)

de Amorim et al. (71)	N	N	U	N	U	Y	N	N	NA	LOW (1)
de Sá et al. (48)	N	N	U	N	U	Y	N	N	NA	LOW (1)
Drenski et al. (49)	Y	N	U	Y	U	Y	N	N	NA	LOW (3)
Fuentes et al. (72)	N	N	U	N	N	Y	Y	N	NA	LOW (2)
Goncalves-Filho et al. (50)	Y	N	U	Y	U	Y	N	N	NA	LOW (3)
Grisar et al. (73)	N	N	U	Y	U	Y	N	N	NA	LOW (2)
Hamasha et al. (4)	Y	N	U	Y	U	Y	N	N	NA	LOW (3)
Kashmoola et al. (51)	N	N	U	N	U	Y	N	Y	NA	LOW (2)
Kenawi et al. (74)	Y	N	U	Y	U	Y	N	N	NA	LOW (3)
Kuzekanani et al. (75)	Y	N	U	Y	U	Y	N	N	NA	LOW (3)
Ledesma-Montes et al. (52)	Y	Y	U	Y	U	Y	N	N	NA	LOW (4)
Lyu et al. (53)	N	N	U	N	U	Y	N	N	NA	LOW (1)
Malčić et al. (5)	Y	N	U	Y	U	Y	N	N	NA	LOW (3)
Mateo-Castillo et al. (54)	N	N	U	N	U	Y	Y	N	NA	LOW (2)

Miloglu et al. (55)	Y	N	U	Y	U	Y	N	N	NA	LOW (3)
Mir et al. (56)	N	N	U	N	U	Y	N	N	NA	LOW (1)
Nabavizadeh et al. (57)	Y	Y	U	Y	U	Y	N	N	NA	LOW (4)
Omal et al. (58)	Y	Y	U	Y	U	Y	N	N	NA	LOW (4)
Pisek et al. (59)	Y	N	Y	Y	U	Y	Y	Y	NA	MODERATE (6)
Saberi et al. (60)	Y	N	U	Y	U	Y	N	N	NA	LOW (3)
Sahebi et al. (70)	Y	N	U	Y	U	Y	Y	N	NA	LOW (4)
Sener et al. (61)	N	N	U	N	U	Y	N	N	NA	LOW (1)
Shayan et al. (62)	Y	N	U	Y	U	Y	N	N	NA	LOW (3)
Shetty et al. (63)	Y	Y	U	Y	U	Y	N	N	NA	LOW (4)
Simsek et al. (65)	Y	N	Y	Y	Y	Y	Y	N	NA	MODERATE (6)
Sobral et al. (66)	Y	N	U	Y	U	Y	N	N	NA	LOW (3)
Taschieri et al. (76)	N	N	U	N	U	Y	N	N	NA	LOW (1)
Udoye et al. (67)	Y	N	U	Y	U	Y	N	N	NA	LOW (3)
Uslu et al. (68)	N	N	U	N	U	Y	Y	N	NA	LOW (2)
Weckwerth et al. (69)	N	N	U	N	U	Y	Y	N	NA	LOW (2)

CASE SERIES

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Regenerative endodontic treatment in permanent immature teeth: Case series

Buket Beytaş Algan, Mustafa Murat Kocak

Department of Endodontics, Zonguldak Bülent Ecevit University Faculty of Dentistry, Zonguldak, Turkiye

Regenerative endodontic treatment is a biologically based procedure primarily indicated for the management of necrotic immature permanent teeth. Beyond achieving the resolution of periapical radiolucencies and the elimination of clinical symptoms, RET aims to promote continued root development, including the thickening of dentinal walls and apical closure, and ideally, the re-establishment of pulp vitality. This case report presents two clinical cases treated with regenerative endodontic protocols, with follow-up periods of 30 months and 12 months, respectively. The first case involves a maxillary lateral incisor that underwent a repeated regenerative procedure, while the second case pertains to a maxillary central incisor with a history of dental trauma and prior conventional root canal treatment. The irrigation protocol consisted of 1.5% sodium hypochlorite, followed by distilled water and 17% ethylenediaminetetraacetic acid. Calcium hydroxide was employed as the intracanal medicament. Biodentine (Septodont, France) was used as a coronal barrier, and definitive restorations were completed with composite resin. During the follow-up period, a secondary regenerative procedure was performed for Case 1 at the 18-month recall. At the 30-month follow-up for Case 1 and the 12-month follow-up for Case 2, both cases exhibited radiographic evidence of periapical healing and remained asymptomatic. However, both teeth yielded negative responses to pulp vitality testing and cold stimuli. Regenerative endodontic treatment is considered a promising alternative to apexification therapy for immature and necrotic teeth.

Keywords: Platelet-rich fibrine; regeneration; revascularization.

Introduction

The treatment of permanent teeth with necrotic pulp, periapical lesions, and immature root development presents a significant challenge in clinical endodontics. Consequences of incomplete root development include thin dentinal wall, open apex, and inadequate root length, which predispose the teeth to a fracture (1). The absence of an apical constriction complicates endodontic therapy, as it hinders the effective sealing of the root canal system using conventional obturation techniques (2).

Historically, apexification using calcium hydroxide over multiple visits was the preferred approach to induce the formation of an apical hard tissue barrier in such teeth (3). However, with the introduction of mineral trioxide aggregate (MTA), studies have demonstrated its ability to form a well-sealed, high-quality barrier in the apical third of the root with a significant success rate (4). While apexification can achieve apical closure through calcific barrier forma-

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Correspondence: Buket Beytaş Algan. Department of Endodontics, Faculty of Dentistry, Zonguldak Bülent Ecevit University, Zonguldak, Türkiye

Tel: +90 536 – 506 01 99 e-mail: buketbeytasalgan@gmail.com

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tion, it does not facilitate continued root development or reinforcement of root structure (2).

As an alternative approach, biologically based endodontic procedures have been developed with the goal of regenerating a functional pulp–dentin complex (5). Commonly referred to in the literature as revascularization or Regenerative endodontic treatment (RET) (6), this approach aims to stimulate the ingrowth of stem cells from the apical papilla, facilitating a pulp-like tissue formation within the root canal system. In addition to alleviating pain and inflammation, RET promotes healing of periapical lesions (7).

Recent advances in tissue engineering have emphasized three essential components for successful regeneration: Adult stem cells, signaling molecules, and a three-dimensional (3D) scaffold capable of supporting cellular growth and differentiation (8). Traditionally, the formation of a blood clot—stimulated by deliberate instrumentation beyond the open apex of an immature root—serves as the primary scaffold in RET (9). In this context, biological scaffolds such as platelet-rich plasma (PRP) and platelet-rich fibrin (PRF) have been extensively investigated due to their ability to promote healing, support tissue regeneration, and modulate immune responses (10).

The steps in regenerative endodontics typically include: (i) Minimal or no mechanical instrumentation of dentinal walls, (ii) chemical disinfection using irrigants, (iii) intracanal medication, (iv) induction of intracanal bleeding to form a blood clot, (v) sealing with a hydraulic calcium silicate-based cement, and (vi) placement of a coronal restoration to ensure an effective seal (6).

This case report aimed to present the management of two clinical cases with regenerative endodontic procedures and follow-up periods.

Case Presentations

Case 1

A 15-year-old systemically healthy female patient referred with a complaint of fistulization and purulent discharge in tooth #12. Clinical examination revealed the presence of a sinus tract, with no tenderness to percussion or palpation. Radiographic evaluation showed an open apex, a periapical radiolucent lesion associated with tooth #12, and the presence of Type II dens invaginatus (Fig. 1a) (Panoramic radiography device (J. Morita MFG. CORP., Kyoto, Japan), periapical radiography device (J. Morita MFG. CORP., Kyoto, Japan), CBCT (NewTom VGIevo, Cefla, Imola, Italy)). Written informed consent was obtained from the patient's family.

Due to the immature root structure and the anatomical complexity posed by the invaginated portion of the tooth, which could complicate apexification with MTA, RET was planned. Following informed consent, access cavity preparation was performed under rubber dam isolation. The main canal was reached through the center of the invaginated area, and working length was established. Without any mechanical instrumentation, irrigation was carried out using 20 mL of 1.5% sodium hypochlorite (NaOCl), 20 mL of distilled water, and 10 mL of 17% ethylenediaminetetraacetic acid (EDTA) (11). The canals were dried with sterile paper points, and calcium hydroxide was placed as the intracanal medicament. Temporary restoration was completed with conventional glass ionomer cement.

At the second visit, three weeks later, the sinus tract had resolved and the tooth was asymptomatic. Local anesthesia without vasoconstrictor (3% Safecaine) was administered. Irrigation was repeated using 20 mL of 17% EDTA and 20 mL of distilled water. After drying the canal, apical pa-

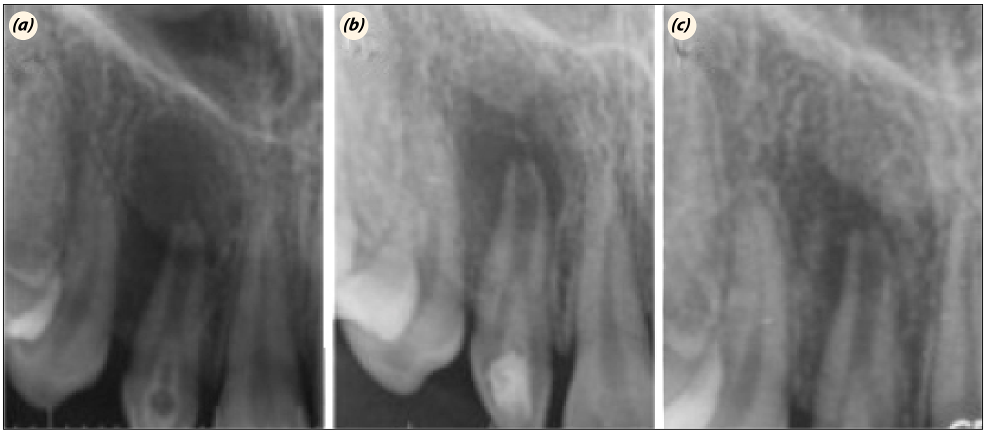

Fig. 1. Radiographic images of Case 1: **a)** Pre-treatment radiograph, **b)** 18-month follow-up radiograph, **c)** 30-month follow-up radiograph.

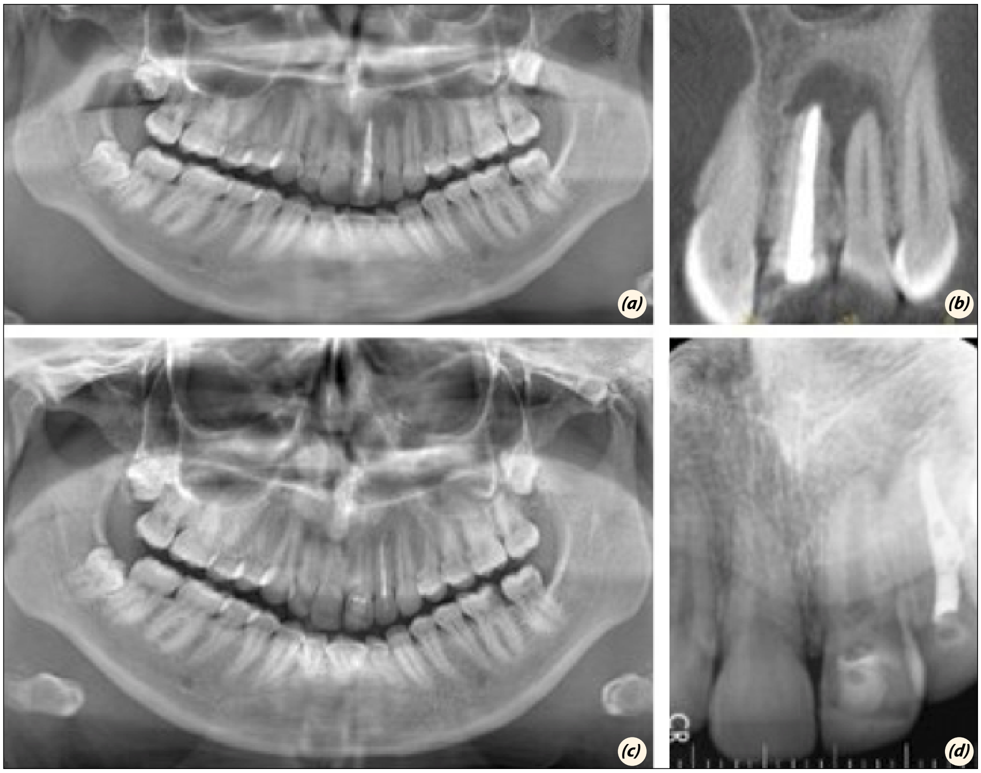

Fig. 2. Radiographic and tomographic images of Case 2: **a)** Pre-treatment panoramic radiograph, **b)** Pre-treatment CBCT, **c)** 12-month follow-up panoramic radiograph, **d)** 12-month follow-up periapical radiograph.

tency was extended by 3–4 mm using a #20 K-file due to the size of the lesion. Since effective intracanal bleeding was unlikely, platelet-rich fibrin (PRF) prepared prior to the procedure (Medifuge centrifuge (Silfradent S.r.l., Forlì, Italy), 2700 rpm, 12 minutes) was introduced into the canal space. The invaginated portion was sealed with Biodentine (Septodont, France), followed by placement of a resin-modified glass ionomer base, and the tooth was permanently restored with composite resin.

At follow-up visits, the tooth remained asymptomatic, and radiographic imaging showed a reduction in lesion size. However, no response was elicited to pulp vitality or cold testing. At the 18-month follow-up, a fistulization was detected. Given the previous reduction in lesion size (Fig. 1b), it was assumed that more effective bleeding could be achieved. Therefore, a second regenerative procedure was planned. Using a dental operating microscope (Leica Microsystems, Wetzlar, Germany) and ultrasonic tips (ED7, Guilin Woodpecker Medical, China), the Biodentine barrier was carefully removed. The same irrigation, medication, treatment, and obturation protocols were repeated.

At the 30-month follow-up, clinical examination revealed no sensitivity to percussion or palpation, and no signs of a sinus tract were observed. The size of the periapical lesion was remarkably reduced which was evident in radiographs (Fig. 1c). However, no significant thickening of the root canal walls was detected, and pulp vitality testing continued to yield negative results.

Case 2

A 22-year-old systemically healthy female patient referred with a complaint of pain in tooth #21. Medical history revealed a traumatic dental injury approximately 10 years earlier. Clinical examination showed tenderness to percussion in tooth #21. Radiographic evaluation revealed that tooth #21 was immature and previously treated endodontically, and there was a large periapical radiolucent lesion extending around the apices of both teeth #21 and #22 (Fig. 2a; Fig. 2b). Tooth #22 was nonresponsive to both cold and electric pulp tests. Written informed consent was obtained from the patient.

Given the incomplete root development of tooth #21, RET was planned, while conventional root canal therapy was indicated for tooth #22. During the first appointment, the existing root canal filling in tooth #21 was removed using mechanical techniques. An access cavity was prepared in tooth #22. Both teeth were irrigated with 20 mL of 1.5% NaOCl, 20 mL of distilled water, and 10 mL of 17%

EDTA, all activated ultrasonically. Calcium hydroxide was placed as the intracanal medicament, and the patient was scheduled for a second visit four weeks later.

At the second visit, both teeth were asymptomatic. For tooth #21, the same regenerative endodontic procedure, as described in Case 1, was performed under rubber-dam isolation. The root canal treatment for tooth #22 was completed using conventional techniques.

The follow-ups were performed at 1, 3, 6, and 12 month periods. At the 12-month follow-up, both teeth remained asymptomatic. Radiographic imaging showed resolution of the radiolucent lesion and apical closure of tooth #21 (Fig. 2c; Fig. 2d). However, no response to pulp vitality or cold testing was observed in tooth #21.

Discussion

Dental pulp necrosis may result from various etiological factors, including traumatic injuries, extensive carious lesions, and developmental anomalies (dens evaginatus/dens invaginatus). These insults can interrupt root development, leading to incomplete maturation of the affected teeth. Koç et al. (12), reported that there is no evidence that pulp necrosis etiology affected RET results. However, according to the findings of Hu et al. (13), teeth with developmental dental anomalies demonstrated a more favorable prognosis following RET compared to teeth with trauma-induced pulp necrosis (13). Geisler suggested that the outcomes of RET may vary depending on whether the affected teeth exhibit partial or total pulpal necrosis (14). Huang further proposed that the mode of pulpal regeneration is influenced by these distinct clinical conditions (15). In cases of partial necrosis, the remaining vital pulp tissue may hypothetically recover following disinfection and contribute to the regeneration of the damaged portion, thereby offering a more favorable prognosis. Conversely, in cases of complete pulpal necrosis, where de novo pulp tissue synthesis is required, the prognosis is generally less favorable and may necessitate the use of alternative protocols and scaffolding materials (14,15).

The present case series examined the clinical efficacy of PRF as a scaffold in de novo regeneration scenarios, in addition to apical bleeding. In Case 1, recurrent fistulization was observed at the 18-month follow-up, which was attributed to inadequate apical bleeding likely caused by the extensive size of the apical radiolucency. After retreatment, all clinical signs and symptoms had resolved by the 30-month recall, and the tooth remained functional.

In Case 2, the RET was performed on a tooth with previous root canal treatment. At the 12-month follow-up, clinical symptoms had completely disappeared, while the tooth remained functional. In both cases, apical closure was observed; however, no significant increase in root wall thickness was recorded. Furthermore, electric pulp testing and cold stimulation tests demonstrated negative responses for both teeth.

Effective bacterial elimination from the root canal system plays a crucial role in the success of revascularization, as the presence of infection can disrupt the regenerative process (16). The local application of triple antibiotic paste (a combination of metronidazole, ciprofloxacin, and minocycline) was demonstrated to be effective in eliminating endodontic pathogens from infected root canals, both in vitro (17) and in vivo (18) conditions. Calcium hydroxide has also been shown to be an effective intracanal medicament (19). In both presented cases, calcium hydroxide was selected over triple antibiotic paste due to several disadvantages of the antibiotic paste including; the risk of tooth discoloration (20), potential for bacterial resistance (21), difficulty in complete removal from the canal system (21), and greater cytotoxicity toward stem cells (22).

Jadhav et al. (23) found PRP to be more effective than blood clots in regenerative procedures. The superiority to PRP's was related to collagen production stimulation, sustainable release of growth factors, and enhanced proliferation of undifferentiated mesenchymal and endothelial cells from the periapical area (23). In a clinical investigation involving 16 necrotic immature permanent maxillary incisors, Sharma et al. (24) evaluated the efficacy of RET. Their findings revealed significant improvements in periapical tissue repair, apical closure, root elongation, and increased dentinal wall thickness. Notably, the use of PRF yielded superior outcomes compared to the blood clot scaffold, particularly in promoting periapical healing, facilitating apical closure, and enhancing dentinal wall reinforcement. Platelet-rich plasma (PRP) is administered into the root canal space, where it subsequently undergoes coagulation. In contrast, platelet-rich fibrin (PRF) is derived from whole blood without the use of anticoagulants, platelet activators, or their antagonists, employing a single-step centrifugation process. During this procedure, the platelets are naturally activated and become incorporated into a developing fibrin matrix. The resulting fibrin clot is then harvested and introduced into the root canal system. Compared to PRP, PRF offers a more cost-effective and technically straightforward alternative, as its preparation does not require any exogenous biochemical agents. Due to the initiation of platelet activation during the centrifugation process, the preparation of platelet-rich fibrin (PRF) is considered technique-sensitive, requiring prompt clinical application of the final product to preserve its biological efficacy (9). In the present cases, due to the large size of the apical radiolucencies and the concern that adequate bleeding might not be achieved, PRF was prepared from the patient's blood prior to the procedure and introduced into the canal space as a scaffold. According to the 12 and 30 months follow-ups of both cases, the application of PRF demonstrated successful results and can be used in the treatment of necrotic and immature teeth similar to the PRP.

The RET aims to maintain the function of the involved tooth and demonstrate favorable healing outcomes. Several earlier studies have reported satisfactory root maturation despite the treated teeth exhibiting no response to pulp sensibility tests. This paradox may be attributed to histological evidence indicating that the tissue formed following regenerative endodontic procedures often resembles periodontal or bone-like structures, rather than a true pulp–dentin complex (25). Responses to vitality tests can be misleading depending on the use of EDTA and the thickness of the barrier material employed (26). It is important to note that the absence of a pulp response does not necessarily indicate the absence of vitality (27). Moreover, the newly formed pulp-like tissue may possess an immature or insufficiently developed neural network, potentially leading to a delayed or absent response during pulp sensibility testing (26).

The absence of CBCT at the follow-up sessions may limit the ability to comprehensively evaluate three-dimensional healing outcomes, such as root wall thickening or resolution of periapical pathology.

Conclusion

At the follow-up sessions both Case 1 and Case 2 represented radiographically periapical healing, teeth were asymptomatic and in function, on the other hand vitality test responses were negative. Although these procedures represent a promising alternative to apexification treatments, long-term follow-up and further evidence-based studies are necessary.

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Use of AI for Writing Assistance: Not declared

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Conflict of Interest: None declared.

Ethical Approval: Ethical approval was not required for this study.

Informed consent: Written informed consent was obtained from patients who participated in this study.

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CASE SERIES

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A trilogy tale: Middle mesial canals in permanent mandibular molars - A case series

Dyuti Sikdar, Smriti Rohilla, Arvinder Pal Singh, Himani Lau, Malika Chaudhary

Department of Conservative Dentistry and Endodontics, Bhojia Dental College and Hospital, Baddi, India

The mandibular molars are often conferred with varied anatomies and are more prone to be subject to an endodontic intervention. Therefore, familiarity with these varying aberrant morphologies is of utmost importance to an endodontist. The complex anatomy of permanent mandibular molars, particularly the existence of the middle mesial canals (MMCs), presents significant challenges in endodontic treatment. MMCs can be classified into one of the three types: Fin, confluent, and independent, with the last being the rarest. Inadequacy to identify and treat these canals can precipitate persistent infection and subsequent endodontic failure. This article presents three clinical cases elucidating the detection and management of MMCs in permanent mandibular molars. Advanced diagnostic techniques, including magnification, ultrasonic troughing, and cone-beam computed tomography, can be diligently used to locate and negotiate these canals. All cases involved meticulous cleaning, shaping, and obturation, resulting in successful outcomes. The discussion emphasizes the importance of a systematic approach to canal exploration, the use of modern imaging modalities, and conservative instrumentation to preserve root integrity. The identification and treatment of MMCs are critical for predictable endodontic outcomes. This article underscores the significance of MMCs in endodontics and provides practical insights for their management.

Keywords: Cone-beam computed tomography; endodontic failure; middle mesial canal; permanent mandibular molars; root canal anatomy.

Introduction

The ultimate goal of endodontology is to avert and eradicate apical periodontitis and promote periradicular tissue healing (1). It aims for the reduction of bacterial load and a hermetic three-dimensional filling of the canals. The intricate anatomy of mandibular molars has long posed a challenge in endodontics, particularly with the identification and management of accessory canals. One such aberrancy is the middle mesial canal (MMC) located in the mesial roots of permanent mandibular molars, which has been a subject of intrigue and clinical importance in endodontics. First elaborated by Vertucci et al. (2) and Barker et al. (3) in 1974, the MMC is often overlooked due to its elusive nature and the challenges associated with its detection. A meta-analysis conducted by Al-Maswary et al. (4) in 2023 revealed that the global occurrence of the MMC is 4.4% in permanent mandibular first molars and 1.3% in permanent mandibular second molars. These findings highlight the importance of increased awareness and care-

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Correspondence: Smriti Rohilla. Department of Conservative Dentistry & Endodontics Bhojia Dental College and Hospital, Baddi, Himachal Pradesh, India.

Tel: +91 895 – 833 33 24 e-mail: rohilla.smriti1989@gmail.com

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ful exploration during endodontic treatments to ensure proper identification and management of such anatomical variations.

In a groundbreaking clinical study examining 100 permanent mandibular molars, Pomeranz et al. (5) discovered MMCs in 12 permanent molars and classified them into three distinct morphological types:

Fin: Characterized by the ability of an instrument to freely pass in between the mesiobuccal (MB) or mesiolingual (ML) canal and the MMC.

Confluent: Defined by the MMC originating separately but merging apically with either the MB or ML canal.

Independent: Identified by the MMC originating and terminating as a separate entity with its own foramen.

Goel et al. (6) reported that 15% of permanent mandibular first molars exhibited MMCs in their specimens. Interestingly, only 6.7% of these canals were classified as independent, emphasizing the rarity of distinct MMCs with a separate origin and foramen.

The identification and management of MMCs demand the use of advanced diagnostic tools and a deep comprehension of root canal anatomy. Inability to locate and treat these canals can have dire consequences in the form of persistent infections, unsuccessful treatment outcomes or the necessitation for retreatment. Another factor to pay attention to while dealing with MMCs is the concept of danger zone. The danger zone in mandibular molars refers to the distal aspect of the mesial root, which consists of a thin, straight layer of dentin. This area is particularly vulnerable to strip perforation during root canal instrumentation. The concept of the danger zone and safety zone in mandibular molars was first introduced by Abou-Rass, Frank, and Glick, highlighting their critical role in ensuring safe and effective cleaning and shaping procedures (7). With ongoing advancements in imaging technologies and endodontic instrumentation, clinicians are increasingly equipped to detect and effectively treat these challenging anatomical variations.

This article delves into the morphology, diagnostic considerations, and clinical strategies for addressing MMCs in mandibular molars, providing insights into their significance in achieving predictable endodontic outcomes.

Case Presentation

Case 1

A 16-year-old male patient visited the Restorative and Endodontic Clinic, complaining of spontaneous pain in the lower right molar region. The medical history of the patient was non-contributory. Upon intraoral examination, extensive caries was identified in the permanent right mandibular first molar (Fig. 1A). A radiographic examination using Kodak RVG 5100 sensor (Carestream Health, Inc., Rochester, NY, USA) operated at 70kVp, 8mA with an exposure time of 0.4 sec revealed deep caries in the tooth and no specific pathosis in its periapical tissues (Fig. 1B). Additionally, a moderate periodontal issue was observed in the first molar, and the tooth exhibited tender-

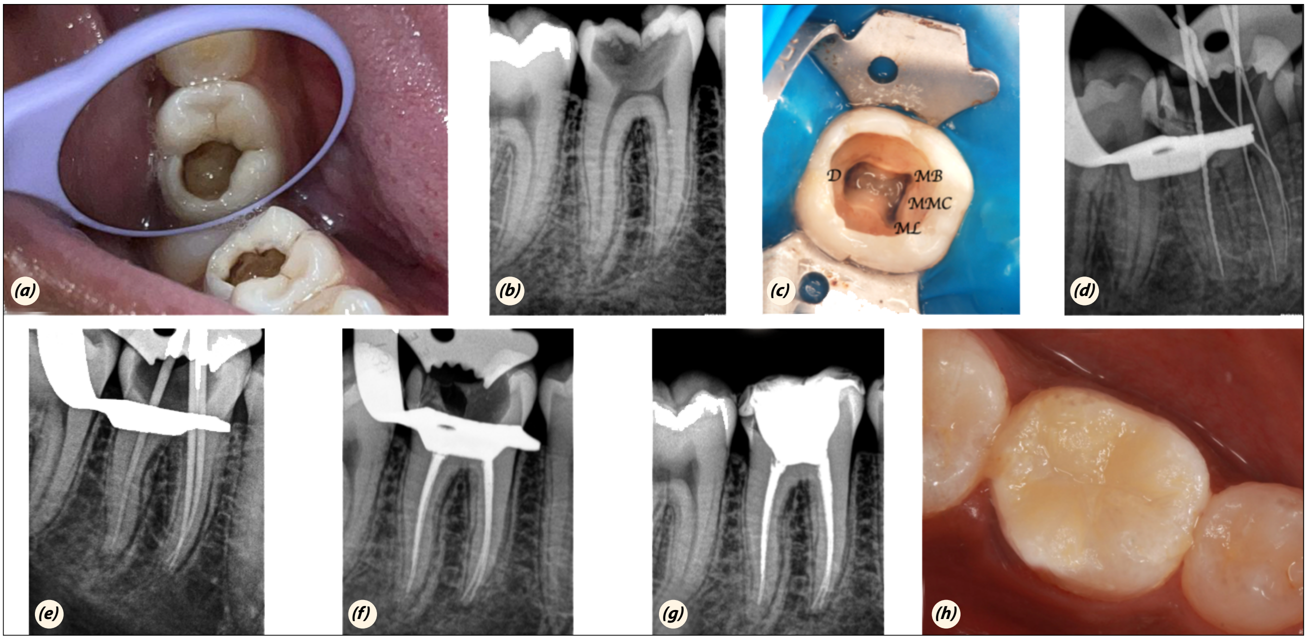

Fig. 1. **a)** Preoperative clinical picture; **b**) Preoperative radiograph #46; **c**) Middle mesial canal; **d**) Working length determination; **e**) Master cone; **f**) Obturation; **g&h**) Post obturation restoration.

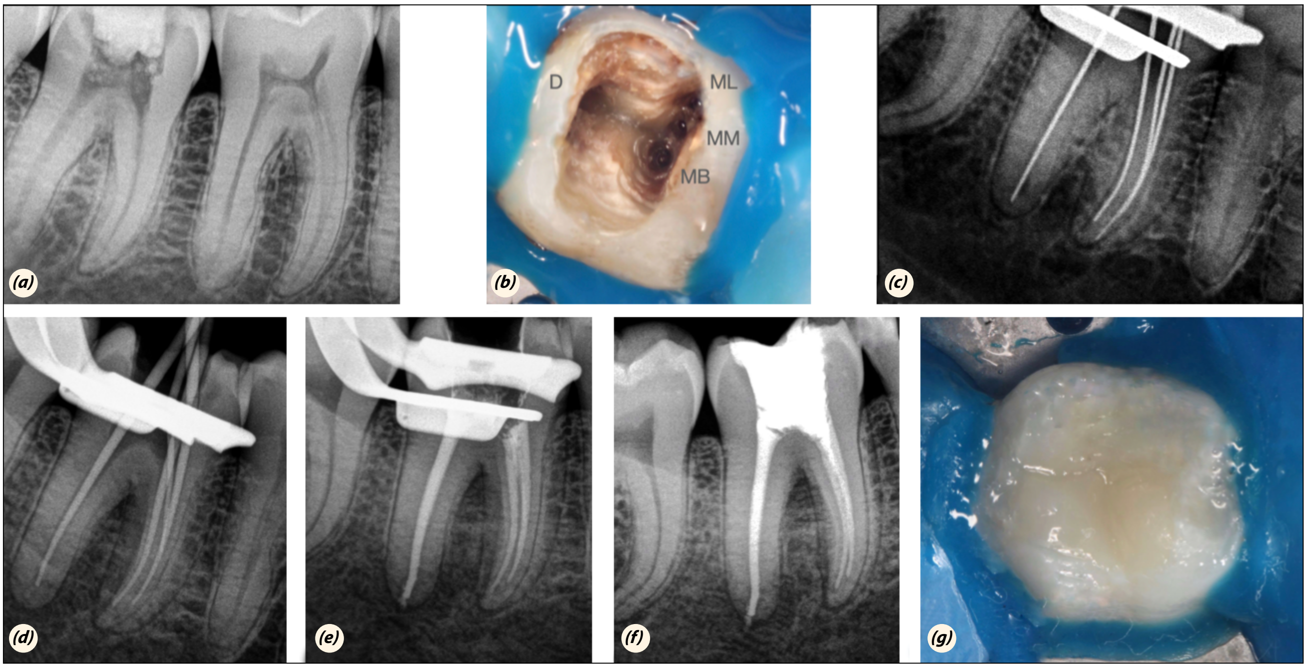

Fig. 2. **a)** Preoperative radiograph #47; **b)** Middle mesial canal; **c)** Working length determination; **d)** Master cone; **e)** Obturation; **f&g)** Post obturation restoration.

ness on percussion. The tooth gave a delayed response to electric pulp tester (EPT). Based on the clinical and radiographic findings, a diagnosis of chronic irreversible pulpitis with symptomatic apical periodontitis in tooth 46 owing to caries was confirmed. An informed consent was obtained before commencing the treatment. After isolating the tooth with a rubber dam, the dental caries was excavated employing diamond burs, and proper endodontic access was achieved. Following thorough irrigation of the pulp chamber, inspection of the chamber floor revealed orifices corresponding to the MB, ML, and distal canals (Fig. 1C).

A thorough examination of the groove between the MB and ML canal orifices using troughing with ultrasonic tip led to the localization of the MMC orifice, which was then subsequently negotiated. The working lengths were taken with the aid of an electronic apex locator (Root ZX; Morita, Tokyo, Japan) and verified radiographically (Fig. 1D). The MMC was found to be of confluent type joining with ML canal apically.

All canals were prepared using NeoEndo Flex rotary instruments (Orikam Healthcare India Private Limited) up to #25, 4% for rest of canals and #20, 4% for MMC with copious irrigation using 3% sodium hypochlorite (NaOCl), 17% ethylenediaminetetraacetic acid (EDTA), and saline. The irrigants were activated with EndoActivator for 30 seconds each time. The canals were then dried with sterile paper points, calcium hydroxide (CH) was placed, and the tooth was temporarily restored with teflon tape (PTFE) and Cavit (Dentsply Sirona). The minimal preparation of the MMC was done to avoid chances of strip perforation in the danger zone.

At the next visit which was one week later, the tooth had become completely asymptomatic. Following verification of the master cones (Fig. 1E), the canals were obturated and sealed with AH Plus sealer (Dentsply DeTrey GmbH, Konstanz, Germany) and gutta-percha (Fig. 1F). A definitive post-endodontic restoration was performed to ensure a good coronal seal and the patient reported no postoperative complications (Fig. 1G; Fig. H).

Case 2

A male patient, 27 years of age, with no significant medical history, came in with pain in the lower right back tooth region. He reported having undergone a restoration procedure five days prior in his native village. A radiograph captured with Kodak RVG 5100 sensor (Carestream Health, Inc., Rochester, NY, USA) operated at 70kVp, 8mA with an exposure time of 0.4 sec revealed a previously initiated RCT in tooth 47 (Fig. 2A). The periodontium was also affected, and the tooth exhibited tenderness to percussion. The tooth showed no response to EPT. A diagnosis of previously initiated root canal therapy with symptomatic apical periodontitis was made. Informed consent was taken before initiating the treatment. After rubber dam isolation of the tooth, the existing restoration was removed, and proper endodontic access was established. Following thorough irrigation of the pulp chamber with 3% NaOCl, inspection of the chamber floor revealed orifices belonging to the MB, ML, and distal canals. The groove extending between the mesiobuccal and mesiolingual canal orifices was carefully examined with a DG-16 probe which led to the discovery of the MMC orifice, which was then negotiated (Fig. 2B). An electronic apex locator (Root ZX; Morita, Tokyo, Japan) was employed to measure the working lengths and verified radiographically. The MMC was confluent with the MLC (Fig. 2C).

The canals were debrided and shaped with the NeoEndo Flex rotary instruments (Orikam Healthcare India Private Limited) up to #25, 4% for all canals except the MMC which was instrumented up to #20, 4% with intermittent irrigation copiously using 3% NaOCl and saline. The irrigants were activated with EndoActivator for 30 seconds each time. The canals were dried with sterile paper points and CH was introduced for one week. The tooth was temporarily restored with PTFE tape in the pulp chamber followed by Cavit (Dentsply Sirona). Minimal preparation of MMC aided in avoiding any iatrogenic perforations in the danger zone.

At the subsequent appointment, the patient reported as asymptomatic. Following verification of the master cone length, the canals were obturated and the sealer used was bioceramic sealer (Bio – C, Angelus) (Fig. 2D; Fig. 2 E). A definitive post endodontic restoration was performed with composite resin and the patient reported no post-operative complications (Fig. 2F; Fig. 2G).

Case 3

A female patient, 16 years of age, with no significant medical history walked into the Department of Conservative Dentistry and Endodontics with a 3–4-day history of pain in the lower right back tooth region. Clinical examination revealed deep occlusal caries in tooth 46, which showed positive responsiveness to EPT and was tender to percussion. Radiographic findings showed occlusal caries approaching the pulp, periradicular radiolucency, and ir-

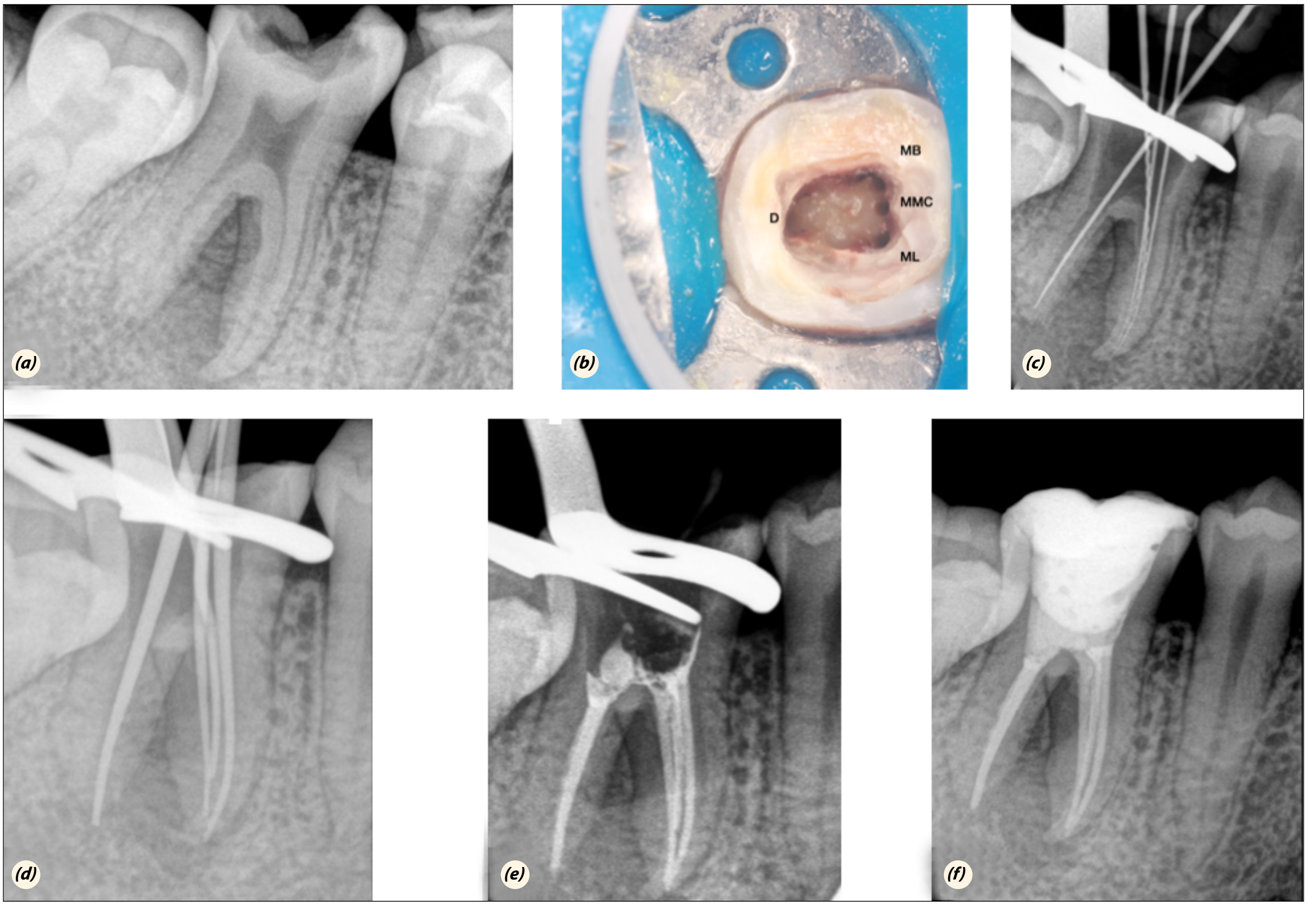

Fig. 3. **a)** Preoperative radiograph #46; **b)** Middle mesial canal; **c)** Working length determination; **d)** Master cone; **e)** Obturation; **g)** Post obturation restoration.

regular root outlines suggestive of external inflammatory resorption, leading to a final diagnosis of chronic irreversible pulpitis with symptomatic apical periodontitis due to caries in 46 and external inflammatory root resorption owing to caries in 46 (Fig. 3A). The RVG was captured using Kodak RVG 5100 sensor (Carestream Health, Inc., Rochester, NY, USA) operated at 70kVp, 8mA with an exposure time of 0.4 sec. Informed consent was taken before the treatment was commenced. After administering local anesthesia and achieving rubber dam isolation, the caries was excavated, and an endodontic access cavity prepared. Inspection of the pulp chamber floor revealed four canal orifices: MB, MM, ML, and distal, with the MMC being confluent with the MBC (Fig. 3B). All canals were negotiated, and working lengths were determined using an apex locator and confirmed radiographically (Fig. 3C). The canals were instrumented using NeoEndo Flex Rotary Files (Orikam Healthcare India Private Limited) up to #25, 4% for all canals except for MMC which was instrumented up to #20, 4% with copious irrigation using 3% NaOCl and saline which was activated using EndoActivator. After drying the canals with sterile paper points, CH was placed in the canals, and the tooth was temporarily restored with Cavit (Dentsply Sirona).

On the subsequent appointment the patient reported no pain or symptoms. The intracanal dressing of CH was removed with sonic agitation using saline. Drying of the canals was accomplished with sterile paper points and the master cone fit checked radiographically (Fig. 3D). Obturation was carried out using Bio-C sealer (Angelus) (Fig. 3E). A post-endodontic restoration was performed to ensure adequate coronal seal (Fig. 3F; Fig. 3G).

Patient Perspective

All three patients are satisfied with the treatment provided and have been kept on follow up.

Discussion

An incidence of as high as 42% missed root canals have been reported in endodontically treated teeth (8). This significant percentage highlights that variability anatomy of the root is more a rule than an exception. Given such morphological aberrancies, it is crucial for clinicians to go beyond predetermined assumptions surrounding the number of roots and root canals.

In the previous study by Al-Maswary et al. (4), the global frequency of occurrence of MMCs in permanent mandibular first molars, was reported to be 4.4% and that in permanent mandibular second molars to be 1.5%. Bansal et al. (9) revealed much higher prevalence of MMC in mandibular first and second molars, ranging from 16% to 60%. Prevalence of the MMCs was lower (9%) and is at the lower end of the reported range in the international literature as reported by Palottil et al. (10) for an Indian subpopulation. Srivastava et al. (11) found that 24 MMCs were fused with MB and ML and 2 MMCs were independent. Another important factor found in conjunction with the MMC is the occurrence of isthmus in these teeth. According to Tahmasbi et al. (12) as high as 64.7% frequency of isthmus was reported in the mesial roots of mandibular molars. According to Bharatiya et al. (13) there was an almost equal division of male and female patients and the overall prevalence rate for MMC was found to be 8.6%. Therefore, a meticulous and stepwise approach is essential for identifying these anatomical variations. This includes broad anticipation of anomalies, coupled with clinical precision through the use of adequately-exposed and properly processed periapical radiographs taken from multiple angulations, enhanced visualization with Loupes or dental operating microscopes and accessory illumination, the use of front-surface mirrors, optimal access cavity preparation, and a careful intra- and inter-canal exploration. This sort of a diligent approach helps in achieving the best possible outcome for endodontic treatment of teeth.

Krasner and Rankow investigated the relationship between the pulp chamber, the clinical crown, and the pulp chamber floor, establishing a set of laws that provide clinicians with valuable guidance for locating difficult-to-find canals (14). One of the primary reasons for treatment failure in endodontics is the inadequacy to detect additional canals or recognize unusual canal configurations (15,16).

To address these challenges, conservative techniques utilizing an ultrasonic tip or round bur to trough which can effectively remove dentinal protuberances obstructing access to the groove extending between the mesiolingual and mesiobuccal canal orifices. Once access to the developmental groove is achieved, a conscientious examination with the sharp pointed tip of an endodontic explorer often aids in locating the elusive MMC orifice. If a depression or orifice is identified, ultrasonic tips can be used to trough the groove, enabling negotiation of the intermediate canal with a small file. Aside from these, Micro-Openers (Dentsply Maillefer, Switzerland), various dyes like methylene blue, champagne bubble test, endodontic explorers are other methods for detecting extra canals.

Advanced imaging techniques are equally critical. Digital radiographs taken at different angulations provide essential observations regarding canal configurations. La et al. (17) advocated the use of cone-beam computed tomography (CBCT) for the clinical detection and effective management of independent middle mesial canals in permanent mandibular first molars.

The canals can be obturated using single cone technique with appropriate sealer or for a better seal be obturated with warm vertical compaction of gutta percha for the apical 5mm using a downpacking technique with System B and followed by back packing using a thermoplastizing unit (eg. Obtura III, Calamus, Ultrafil 3D etc.) which have been shown to produce a good seal with the least amount of voids in the obturation.

Despite that a number of authors have acquiesced the presence of three orifices in the mesial root, reports of three independent canals remain rare. This additional MMC may either have a separate orifice and remain independent or merge with the mesiobuccal or mesiolingual canal in the apical direction.

Given these anatomical characteristics, the MMC should not be overly enlarged to prevent the risk of perforation as it often has a diameter smaller than the mesiobuccal and mesiolingual canals. Engaging the use of Gates-Glidden drills should be approached with extreme skepticism when necessary to minimize the likelihood of weakening the root structure or better still avoided altogether. A conservative approach to canal preparation is essential to preserve the integrity of the mesial root and ensure successful treatment outcomes.

This case series lags in the aspect of failing to employ the use of CBCT which has been proven to be a useful adjunct in diagnosing aberrant morphologies of root canal systems.

Conclusion

Treating additional aberrant canals presents significant challenges; however, failing to locate and treat these canals is a leading cause of endodontic failures. A thorough investigative radiological evaluation, adjunct by the use of CBCT is greatly helpful in locating the additional aberrant canals. Aided by good visualisation, magnification with loupes or dental operating microscope, a good rubber dam isolation ensures longevity of the endodontic treatment in the long term.

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