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In Memoriam: Prof. CEMİL YEŞİLSOY

The official Journal of Turkish Endodontic Society

In Memory of Prof. Cemil Yeşilsoy…

I am deeply saddened by the loss of a very dear friend, a true scientist, and a devoted citizen of his homeland who loved his country with all his heart.

I have lost not only a friend, but we, as a community, have lost one of Türkiye's most prominent representatives in the field of endodontics in the United States—an exemplary academic who dedicated his life to science, education, and his patients.

Cemil's greatest dream was to return to Türkiye after his retirement to live and work there. Regrettably, he passed away before he could fulfill this dream.

I first met him in 2007 in Pennsylvania during the Annual Session of the American Association of Endodontists (AAE), which I attended as President of the Turkish Endodontic Society. While the President of the AAE was delivering his address on international relations, he recognized the Turkish Endodontic Society ahead of all other international organizations, invited me to the stage, and asked me to invite the General Assembly to participate in our upcoming National Congress.

As I returned to my seat, a young academic approached me.

"I am Cemil Yeşilsoy," he said. "I am a faculty member in the Department of Endodontics at Temple University School of Dentistry. Seeing you represent our country in this manner at such a prestigious international congress deeply moved me. It brought tears to my eyes."

After a brief conversation, he insisted that I cancel my hotel reservation, saying, "From now on, you are staying with me."

Our friendship, which began on that very day, lasted for many years.

We became friends...

We became close companions...

We became brothers...

And we were never apart again.

Whenever we invited him to scientific meetings in Türkiye, he participated with great enthusiasm. Over the years, he generously shared his vast knowledge and experience with our young colleagues without expecting anything in return. He made his lecture notes, presentations, and scientific research freely available to everyone. He always guided and supported our postgraduate residents whom we sent to the United States.

Throughout our friendship, we accumulated countless memories.

We were last together in 2024 at the AAE Annual Session in Los Angeles. Before that, we gathered and shared scientific insights at the AAE meetings in San Francisco (2016), Hawaii (2013), San Diego (2010), Orlando (2009), and Philadelphia (2007).

He made monumental contributions to our country as an invited speaker at scientific meetings organized by the Turkish Endodontic Society, the Turkish Dental Association, and numerous universities.

Prof. Dr. Cemil Yeşilsoy graduated from Ankara University Faculty of Dentistry and completed his advanced specialty training in Endodontics, along with his Master of Science (MS) degree, at the University of Minnesota in 1982. He subsequently earned his Doctor of Dental Medicine (DMD) degree from Temple University.

Throughout his distinguished academic career spanning more than forty years, he served as a faculty member, Clinical Director, Co-Chair of the Department of Endodontics, and Director of the Predoctoral Endodontic Program at Temple University Kornberg School of Dentistry. He also maintained an active clinical practice limited to endodontics in Pennsylvania and New Jersey.

His research on root canal infections, apexification, endodontic biomaterials, canal irrigation, and dental education garnered widespread international recognition. His portfolio of more than thirty scientific publications has been cited thousands of times. His contributions, published in highly respected scientific journals, particularly the Journal of Endodontics, continue to serve as important references today.

Yet, it was not merely his academic accomplishments that made him great.

He was a true scientist, humble, benevolent, delighted to share his knowledge, supportive of the younger generation, and one who never forgot his homeland.

He leaves behind the students he mentored, his scientific works, his enduring friendships, and his exemplary character.

My dear friend...

It was an immense privilege to have known you.

Your memory, your work, and the students you educated will continue to live on.

May you rest in peace.

We will always remember you with love, respect, and deep longing.

May your soul find eternal peace, my cherished friend.

Prof. Seçkin DINDAR

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Turkish Endodontic Journal (TEJ) is the official scientific publication of Turkish Endodontic Society and open access, peer-reviewed international journal. TEJ is published three times per year (May, August, December). The authors are invited to submit original scientific articles, case reports, review articles regarding endodontology and dental traumatology. Letter to the Editor section is also available for authors to write a comment letter on a previously published article in the journal.

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Turkish Endodontic Journal

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Contents

ORIGINAL ARTICLE

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Evaluation of Apical Extrusion Using Xp- Endo Rise, Protaper Ultimate, Trunatomy and One Curve: An In-Vitro Study

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Purpose: This study aimed to evaluate the amount of apical extrusion produced by four contemporary rotary systems (XP-endo Rise, ProTaper Ultimate, TruNatomy, and One Curve). Because apical extrusion is associated with postoperative pain, inflammation, and delayed healing, identifying instrumentation techniques that minimize this phenomenon remains clinically important.

Methods: Eighty extracted human mandibular premolars with <20° curvature were decoronated and mounted on a modified Myers and Montgomery apparatus. Pre-weighed samples were randomly allocated into four groups (n=20) according to the system used. Extruded debris and irrigant were collected in pre-weighed Eppendorf tubes, and the difference between initial and final weights was recorded as the amount of apical extrusion.

Results: All systems produced apical extrusion. ProTaper Ultimate exhibited the highest mean ($0.15\pm0.22\times10^{-4}$ g), followed by TruNatomy ($0.14\pm0.13\times10^{-4}$ g), One Curve ($0.11\pm0.08\times10^{-4}$ g), and XP-endo Rise ($0.08\pm0.05\times10^{-4}$g). Despite these numerical variations, no statistically significant difference was found among the groups (p=0.529).

Conclusion: All rotary systems resulted in apical extrusion, and none demonstrated superiority in minimizing it. These findings suggest that differences in design and kinematics alone may not substantially influence extrusion behavior under standardized conditions.

Keywords: Endodontics; root canal preparation; tooth apex.

Introduction

Apical extrusion of debris is a significant complication of endodontic therapy, leading to postoperative pain, acute inflammatory responses, and delayed healing (1-3). In particular, disruption of balance in an asymptomatic chronic periradicular lesion caused by such extrusion can provoke an acute inflammatory reaction in an attempt to re-establish equilibrium (4). Given that this phenomenon is clinically undesirable yet difficult to prevent entirely, understanding the factors that influence extrusion remains an important research objective in endodontics. Since kinematics, design, and material of root canal instruments can influence the amount of apical extrusion, numerous studies have aimed to understand and minimize this phenomenon (5-9). However, to the best of our knowledge, no previous study has directly compared apical extrusion among XP-endo Rise, ProTaper Ultimate, TruNatomy, and One Curve.

Cite this article as: Kilimci S, Abat VH, Tanalp J. Evaluation of apical extrusion using Xp- endo rise, protaper ultimate, trunatomy and one curve: An in-vitro study. Turk Endod J 2026;11:125-129.
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Therefore, the aim of this investigation was to quantify the amount of apically extruded debris and irrigant produced by four contemporary rotary systems. The null hypothesis was that there would be no significant difference among the systems with respect to apical extrusion.

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 (10). This study has been conducted in full accordance with Helsinki Declaration of World Medical Association. The informed consent was received from all participants. The study has been reviewed and approved by Yeditepe University Clinical Research Ethics Committee on 05/10/2022 with approval number 2022/1649.

Sample size and preparation

Sample size was determined using G*Power 3.1.9.2 with an effect size of 0.4, a power of 80%, and a significance level of α=0.05. Considering a 5% dropout rate, a total of 80 teeth (20 per group) were required. Eighty extracted human mandibular premolars with a single root, a single canal, fully developed apices, and <20° canal curvature (according to Schneider's method) were selected. These anatomical characteristics were confirmed radiographically, in accordance with previous studies (8,11–13). Teeth with root fracture, calcification, root resorption, or previous endodontic treatment were excluded to ensure morphological standardization. Apical patency was confirmed using a #10 K-file. The initial apical diameter was determined as the largest hand K-file that could reach the working length without resistance. Only teeth with an initial apical diameter corresponding to a #10 or #15 K-file were included.

Samples were decoronated to 15 mm and working length was established by inserting a #10 K-file into the canal until its tip was visible at the apical foramen and subtracting 1 mm from this measurement. All external root surfaces were covered with teflon tape, leaving only the coronal access and apical foramen exposed.

Experimental protocols

The modified Myers and Montgomery model was used (14). Each tooth was embedded into 1.5% agar inside a pre-weighed Eppendorf tube to simulate periapical resistance, as suggested by Lu et al. (15) The experimental workflow of the laboratory procedures is summarized in Figure 1.

All canal preparations were performed by a single experienced operator using an X-smart endodontic motor (Dentsply Sirona, Ballaigues, Switzerland) at manufacturer-recommended settings with Rubber-dam (Coltene/Whaledent, Altstätten, Switzerland) isolation to prevent bias.

Group1: XP-endo Rise (FKG Dentaire, La Chaux-de-Fonds, Switzerland)

Group 2: ProTaper Ultimate (Dentsply Sirona, Ballaigues, Switzerland)

Group 3: TruNatomy (Dentsply Sirona, Ballaigues, Switzerland)

Group 4: One Curve (Micro-Mega, Besançon, France)

Although complete standardization of the final apical diameter was inherently limited due to variations in instrument design and taper, all systems were intentionally used to finish canal preparation with comparable apical sizes. Previous studies have shown that apical enlargement, particularly when combined with greater taper, improves irrigant exchange and cleaning efficacy in the apical third without excessive dentin removal (16,17). Therefore, XP-endo Rise 30/.04, ProTaper Ultimate 25/.08, TruNatomy 26/.04, and One Curve 25/.04 were selected as the final instruments.

All samples were irrigated using a closed-ended, side-vented 30-G NaviTip (Ultradent Products Inc., South Jordan, UT, USA) needle with 20 mL of distilled water. Suction was applied throughout the irrigation procedure. In all groups, the flow rate was maintained at 2.5 mL/min.

To ensure consistency, all procedures were performed by the same operator according to a standardized protocol, including rubber dam isolation.

Determination of extruded debris weight

Following root canal preparation, the extruded material was collected in preweighed Eppendorf tubes and reweighed using an analytical balance with an accuracy of 10^{-4} g (Scaltec Instruments, Göttingen, Germany). Each measurement was performed three times, and the mean value was recorded. The amount of apically extruded material was calculated by subtracting the initial weight from the final weight.

Statistical methods

The data were imported to Statistical Package for Social Sciences (SPSS) for Windows Software, version 16.0 (SPSS Inc., Chicago, IL. USA). Descriptive statistics, including mean, standard deviation, median, minimum, and maximum values, were calculated to summarize the continuous variables. The normality of the data was as-

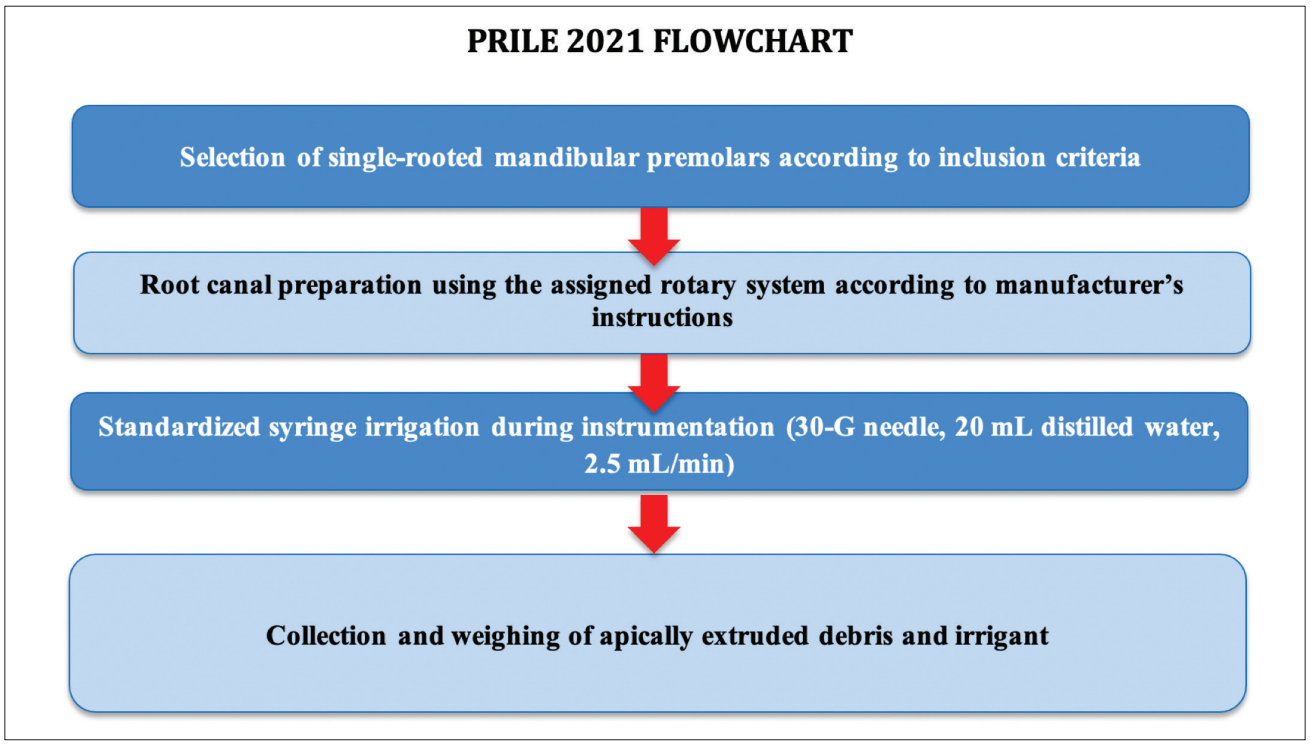

Fig. 1. PRILE 2021 flowchart depicting the sequential experimental procedures of specimen selection and standardization, random group allocation, root canal preparation with the assigned rotary systems under standardized irrigation conditions, and subsequent collection and measurement of apically extruded debris and irrigant.

sessed using the Shapiro–Wilk test. Homogeneity of variances among the groups was evaluated using Levene's test. When the assumptions of normality and homogeneity were met, group comparisons were performed using one-way ANOVA. In cases where these assumptions were not satisfied, the non-parametric Kruskal–Wallis test was applied. A significance level of $p<0.05$ was adopted.

AI declaration

Artificial intelligence–assisted technologies (ChatGPT, Open AI) were used for language polishing. All scientific content, interpretations, and final approval belong to the authors.

Results

All rotary systems produced measurable apical extrusion of debris and irrigant. Descriptive statistics for each group—including mean, standard deviation, median, minimum, and maximum values—are presented in Table 1.

Normality assessment using the Shapiro–Wilk test showed that data in all groups were normally distributed ($p>0.05$). Levene's test indicated that variances were homogeneous across groups ($p>0.05$). Based on these findings, a one-way ANOVA was applied for group comparisons.

According to ANOVA results, there was no statistically significant difference among the four rotary systems regarding the amount of apically extruded debris ($p>0.05$).

Table 1. Descriptive statistics and comparative analysis of the groups (apical extrusion, $\times 10^{-4}$ g)

Group	n	Mean	SD	Median	Minimum	Maximum	p value
XP ENDO RISE	20	0.084390	0.0495288	0.082300	0.0111	0.1938	0.529
PROTAPER ULTIMATE	20	0.150355	0.2139056	0.078250	0.0020	0.8205	
TRUNATOMY	20	0.142895	0.1305755	0.133900	0.0014	0.5348	
ONE CURVE	20	0.109940	0.0787655	0.100100	0.0018	0.3621	

N: number of samples; SD: standard deviation.

The highest mean extrusion value was observed in the ProTaper Ultimate group (0.15 $\times 10^{-4}$ g), followed by TruNatomy (0.14 $\times 10^{-4}$ g), One Curve (0.11 $\times 10^{-4}$ g), and XP-endo Rise (0.08 $\times 10^{-4}$ g). Median and range values demonstrated similar trends, confirming the absence of significant intergroup differences.

Discussion

The present study evaluated the amount of apically extruded debris and irrigant produced by four contemporary NiTi rotary systems. Consistent with the existing literature, all instruments resulted in some degree of extrusion, supporting the widely accepted notion that apical extrusion is an inherent consequence of root canal instrumentation regardless of the technique used (18). This phenomenon is clinically relevant because the presence of debris and irrigants in the periapical tissues may trigger inflammatory responses, flare-ups, and postoperative discomfort (1,2,4).

In the current investigation, no statistically significant difference was observed among XP-endo Rise, ProTaper Ultimate, TruNatomy, and One Curve systems. Although each instrument possesses unique metallurgical properties, cross-sectional geometries and kinematics, these variations did not appear to translate into a measurable difference in extrusion levels. This may be explained by several methodological factors. First, all canals were straight (<20° curvature), and previous research suggests that differences in instrument mechanics tend to be more pronounced in anatomically complex canals, where cutting behavior, contact area, and debris transportation patterns vary more widely (6,8). In relatively simple anatomy, the shaping performance of different systems may converge, reducing the likelihood of significant differences in extrusion.

Although some studies have reported significant differences among various NiTi systems, their methodologies differ in several important respects. Hazar et al. (18) observed reduced extrusion with XP-endo Shaper compared to WaveOne Gold and One Curve in curved canals, likely due to differences in anatomy and kinematics. Cırakoglu et al. (19) found that TruNatomy produced significantly less extrusion than ProTaper systems. El Asfouri et al. (20) reported higher extrusion with ProTaper Universal. However, methodological differences among these studies should be considered, including variations in the use of agar for simulating periapical tissue resistance, the assessment of debris alone or the total extruded material (debris and irrigant), and differences in apical preparation sizes.

Another aspect to consider is the contribution of irrigation parameters. The rationale behind our selection of irrigant was the majority of studies preferring distilled water instead of sodium hypochloride for prevention of crystals (18-20). A standardized irrigation volume, delivery depth, needle type, and flow rate were used in this study. Since irrigation pressure is a major determinant of apical extrusion, strict standardization may have reduced technique-related differences. Furthermore, debris and irrigant were measured together rather than separately. This approach was deliberately chosen to better simulate clinical conditions, where extruded solid debris and irrigating solutions act together in the periapical tissues and collectively contribute to inflammation and postoperative symptoms (2,15). Therefore, measuring totally extruded material provides a more clinically relevant assessment of the potential biological impact of apical extrusion.

The present study is not without limitations. Despite radiographic assessment, minor variations in root canal morphology such as ovality or apical width may have influenced extrusion. While the agar model offers improved simulation of periapical tissue, it does not fully replicate the properties of periapical tissues. Moreover, extruded debris and irrigant were evaluated together, which reflects in vivo inflammatory potential but does not allow quantification of debris separately. Finally, achieving an identical final apical diameter across all systems was inherently not possible due to differences in instrument design and taper. This slight discrepancy in the final apical diameter may have influenced the amount of apical extrusion and should therefore be considered a limitation of the study. Furthermore, XP-endo Rise instruments were used under room temperature conditions without artificial heating. As thermally treated NiTi instruments may exhibit temperature-dependent phase transformation, the absence of body-temperature simulation might have influenced their mechanical behavior and should be considered when interpreting the results (21). Another limitation of this study is that all procedures were performed by a single operator. Although this approach ensured standardization and eliminated inter-operator variability, the inclusion of multiple operators could have reduced potential operator-related bias. Despite these limitations, the findings contribute to the existing body of literature by demonstrating that, under standardized conditions, the four examined rotary systems perform similarly in terms of apical extrusion. This suggests that factors other than instrument choice—such as irrigation control, apical enlargement strategy, and root canal anatomy—may play a more decisive role in determining extrusion levels.

Conclusion

Within the limitations of this in-vitro study, all rotary systems produced apical extrusion, and no statistically significant difference was found among them. The findings

suggest that factors related to instrumentation and irrigation procedures may influence apical extrusion, rather than the specific rotary system used. Further studies using more complex anatomical models are required to better elucidate potential system-related differences.

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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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Bibliometric Analysis of Cone-Beam Computed Tomography Research in Endodontics: A Comparative Evaluation of Web of Science and TR Dizin

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Purpose: Bibliometric analyses are useful for evaluating scientific productivity. However, no study has been reported comparing international and national databases on cone-beam computed tomography (CBCT) in endodontics.

Methods: This study quantitatively analyzed CBCT related endodontic publications indexed in the Web of Science (WoS) and TR Dizin. Data covering 1999–2024 were collected in March 2025 using the keywords "root canal anatomy," "root canal form," "CBCT in endodontics," and "cone-beam computed tomography." Letters to the editor, case reports, and non-endodontic studies were excluded. The WoS dataset was examined for document type, indexing, journal productivity, annual trends, country rankings, and keyword networks, while TR Dizin was evaluated for subject classifications, publication trends, and institutional and city-level research distribution.

Results: A total of 710 CBCT-related publications were found in WoS and 61 in TR Dizin. In WoS, 648 were original articles and 421 were SCI-E indexed. Annual output rose steadily, reaching 45 publications in 2024; Türkiye contributed 9.7% of SCI-E papers. In TR Dizin, 44 publications were research articles, with peaks in 2021 and 2024. Ankara and İstanbul were the leading centers.

Conclusion: Findings show parallel research themes across databases, with Türkiye demonstrating strong and increasing contributions to global CBCT endodontic literature.

Keywords: Bibliometrics; cone-beam computed tomography; databases; bibliographic; endodontics.

Introduction

The morphology of roots and their canals is highly complex, making a thorough understanding of this anatomy essential for successful surgical and endodontic treatments (1).

Root canals rarely consist of a single canal and apical foramen; they often exhibit anatomical variations such as lateral canals, accessory canals, isthmuses, and apical deltas, which can complicate endodontic procedures (2). Studies have shown that root and canal morphology varies significantly across different populations, within the same population, and even among individuals (3).

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Conventional radiographic methods are often limited by image distortion and superimposition, leading to incomplete visualization of root canal systems. The introduction of cone beam computed tomography (CBCT) in dentistry in the early 2000s revolutionized diagnostic imaging by enabling volumetric assessment with minimal radiation exposure (4).

CBCT is an advanced imaging technique that provides highly detailed, three-dimensional visualization of root canal morphology. Unlike traditional two-dimensional radiographs, CBCT offers more accurate imaging across multiple planes, aiding in the planning and execution of endodontic treatments (5). CBCT has been widely applied across various dental fields, including endodontics, restorative dentistry, oral and maxillofacial surgery, periodontology, orthodontics, prosthodontics, and forensic dentistry (6). The evolution of three-dimensional (3D) imaging techniques has significantly improved decision-making in endodontic treatment planning.

Bibliometric evaluations not only reveal publication productivity and collaboration patterns but also identify research hotspots, influential authors, and thematic evolution over time. Such analyses help guide funding priorities and future investigations within a discipline (7,8).

Comparing national and international publication trends offers a broader understanding of how local research priorities align with global scientific progress. This perspective is particularly important for countries like Türkiye, where endodontic research has expanded notably in recent years. However, limited information exists regarding how Türkiye's CBCT related output compares with global patterns. Therefore, this study aims to provide a comprehensive bibliometric evaluation of CBCT research in endodontics by examining temporal trends, contributing countries, subject distributions, and keyword networks across both international and national databases.

Existing bibliometric studies have generally shown a growing global interest in CBCT, reflecting its expanding use in endodontics, oral surgery, and maxillofacial imaging. However, most of these analyses have relied primarily on international databases and have not specifically examined Türkiye's contribution within the scope of endodontic CBCT research. A recent Scopus-based global analysis reported that scientific output in this field is largely concentrated in countries such as Saudi Arabia, India, China, Brazil, Iran, and the United States, while Türkiye also appears among the contributing nations, with 13 publications and 333 citations, reflecting a visible yet comparatively modest presence in the global CBCT literature (3). Taken together, these findings highlight the value of evaluating national research patterns alongside global trends. By integrating data from both Web of Science (WoS) and TR Dizin, the present study addresses this need and provides a combined international and national perspective on CBCT related endodontic research

To our knowledge, this is the first study to conduct a comparative bibliometric assessment of CBCT related endodontic research using TR Dizin.

The hypothesis of this study was that Türkiye's publication trends would parallel global increases in CBCT related endodontic research, and that TR Dizin data would complement WoS findings by providing additional insight into national research productivity.

Materials and Methods

This bibliometric study included publications related to CBCT in endodontics retrieved from the WoS and TR Dizin databases. Searches were conducted in both Turkish and English without time restrictions using the following keywords: ("root canal anatomy" OR "root canal form") AND ("CBCT in endodontics" OR "cone-beam computed tomography"). All records up to 2024 were included, and data were collected in March 2025 and exported as CSV files. Data were collected in March 2025 from publications between 1999 and 2024. Broader search terms were applied to ensure comprehensive coverage. In the analyses conducted on the WoS database, the article language was selected as English.

WoS was selected because it is the most widely used and standardized international database for bibliometric analyses, while TR Dizin was included to represent national scientific output. General keywords were deliberately chosen to maintain consistency between the two databases, as highly specific clinical terms are not indexed uniformly across platforms and may introduce methodological inconsistencies or unintended expansion of the search scope.

Duplicates were identified and removed through DOI and title matching using Microsoft Excel filtering. Letters to the editor, case reports, review articles, and studies unrelated to endodontics were excluded.

Bibliometric network mapping was performed using VOSviewer version 1.6.20 (Center for Science and Technology Studies, Leiden University, The Netherlands; https://www.vosviewer.com/download). The co-occurrence of keywords was analyzed, and their interrelationships over time were visualized through word networks.

The datasets were examined to determine publication types, annual distributions, indexing categories, most productive journals, and contributing countries. For TR Dizin, subject classifications and journal distributions were also analyzed. Additionally, institutional affiliations, city-based productiv-

ity, contributing authors, and international collaborations were examined to provide a more comprehensive overview of national research output. Tables and figures were generated in Microsoft Excel 2021.

This study addressed the following research questions:

1) What is the distribution of CBCT related studies in endodontics?

2) How have CBCT studies in endodontics evolved over the years?

3) What is the country-wise distribution of studies indexed in SCI-E?

4) What is Türkiye's position in global CBCT research in endodontics?

5) What is the annual distribution of CBCT related publications?

6) What are the main subject areas covered in CBCT related endodontic research?

Each research question was linked to specific descriptive analyses and corresponding data presentations in the Results section. Research Questions 1, 2, and 5, which focus on the overall and annual distribution of CBCT related endodontic publications, are primarily addressed through frequency analyses presented in Tables 1–3 and Tables 4–5, as well as Figure 1. Research Questions 3 and 4, which relate to the country-wise distribution of SCI-E indexed studies and Türkiye's position in global CBCT research, are examined in Table 6 and Figure 2. Additional details for Türkiye are illustrated in Figures 3 and 4. Research Question 6, which concerns the main subject areas covered in CBCT related endodontic research, is evaluated using subject classifications and keyword mapping summarized in Table 7 and visualized in Figures 3–5. This structure clarifies how each research question is operationalized and reported in the manuscript.

Results

A total of 710 studies were identified in the WoS database. Among them: 648 Were original research articles, 56 were review articles, 6 were studies in progress, 1 were early access publications, 1 was a book chapter, 1 was a letter to the editor, 1 was a lead article (Table 1).

Of the 648 original research articles, 421 were indexed in WoS SCI-E. The index distribution of these studies is shown in Table 2, while their annual distribution according to WoS Index criteria is provided in Table 3. The top 10 journals publishing the highest number of studies are represented in a treemap chart (Fig. 1).

Distribution of Studies By Country

As shown in Table 6, the top five countries in CBCT related endodontic research collectively produced 240 publications.

The articles' use of "Turkey" and "Türkiye" was consolidated by combining them during the country selection process.

Table 1. Work distributions

Document Types	Count
Article	648
Review	56
Proceedings Paper	6
Early Access	1
Book Chapter	1
Editorial Material	1
Letter	1

Table 2. WoS index distributions

Web of Science Index	Count
WoS. SCI	421
WoS. ESCI	225
WoS. SSCI	8
WoS. ISTP	2
WoS. AHCI	1
WoS. BSCI	1

Table 3. Distribution of publications with SCI-E Criteria by years

Publication Years	Count
2024	45
2023	44
2022	43
2021	44
2020	40
2019	30
2018	20
2017	34
2016	22
2015	23
2014	16
2013	22
2012	9
2011	10
2010	10
2009	5
2008	1
2007	1
1999	1

Fig. 1. Treemap showing the top 10 journals publishing CBCTendodontic studies in the Web of Science database.

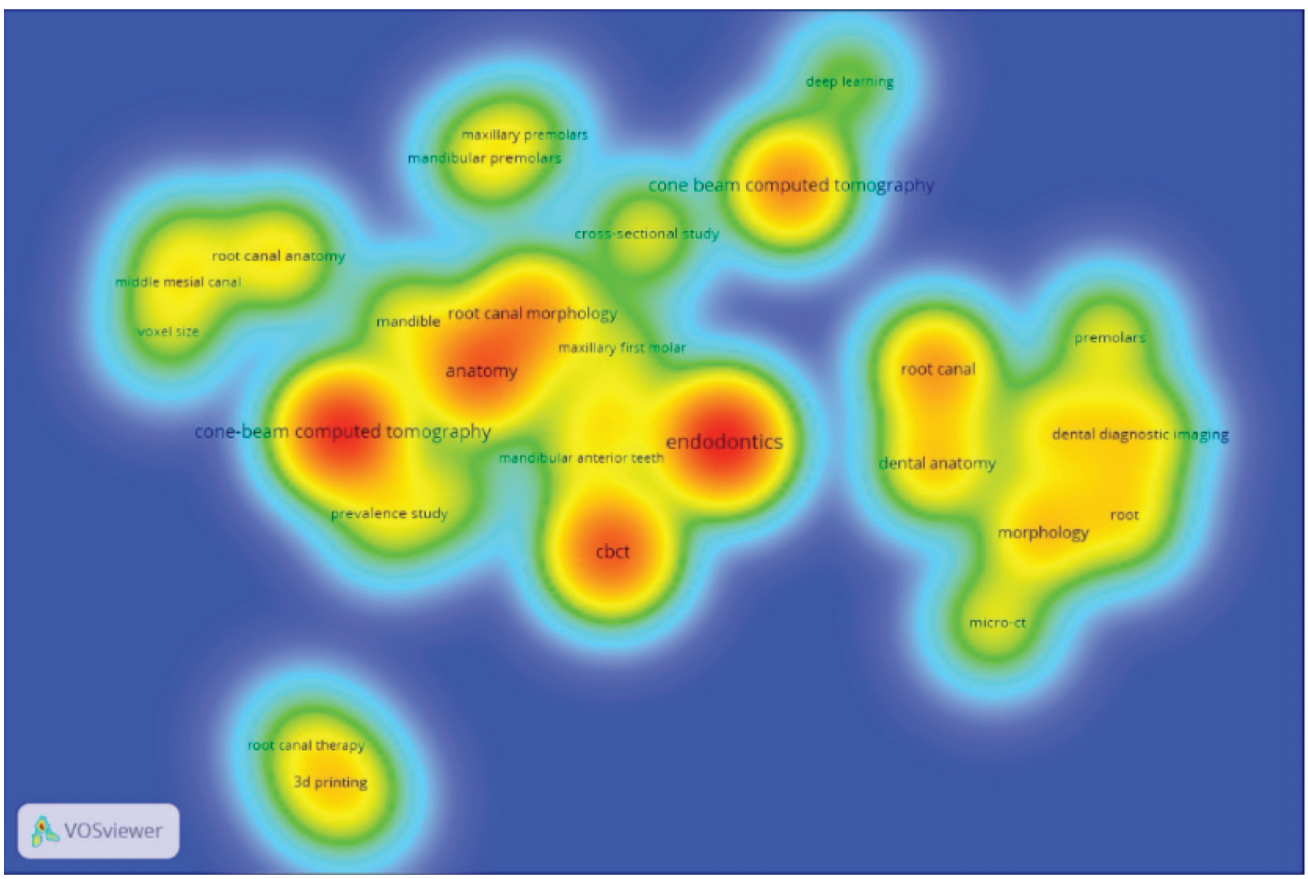

Fig. 2. Term map illustrating the keyword density of the five countries with the highest research output.

Table 4. Distribution of studies in TR DİZİN by years

Years	Count
2024	10
2023	5
2022	4
2021	10
2020	9
2019	4
2018	1
2017	1

Table 5. Distribution of studies published in TR DİZİN by journals

Journal Title	Count
European Endodontic Journal	17
Turkish Endodontic Journal	5
Current Research in Dental Science	3
Clinical and Experimental Health Science	3
Turkiye Klinikleri Journal of Dental Science	3
Clinical Dentistry and Research	2
Cumhuriyet Dental Journal	2
ADO Journal of Clinical Science	1
Bezmialem Science	1
Eastern Journal of Medicine	1
Journal of Health Science and Medicine	1
Online Turkish Journal of Health Sciences	1
Sabiad	1
Selçuk Dental Journal	1
Suleyman Demirel University Journal of Health Sciences	1

Table 6. Number of publications by countries

Country	Count
China	71
Brazil	70
United States of America	53
Türkiye	41
India	36

Table 7. Subject area distribution in TR Dizin

Subject Area	Count
Science > Dentistry > Dentistry	25
Science > Basic Sciences > Microscopy	11
Science > Engineering > Imaging Science & Photography	9
Science > Medicine > Anatomy & Morphology	5
Science > Basic Sciences > Optics	4

Among the 421 SCI-E indexed studies analyzed, the most cited article was the work by Patel et al. (9), which received 352 citations and emphasized the potential applications of cone-beam computed tomography in managing endodontic problems.

Among the top five most productive countries, the most cited publication was by Neelakantan et al. (10), which received 182 citations and compared root canal morphology using CBCT and various radiographic methods.

Keyword Analysis

Keyword co-occurrence analysis was performed for 240 studies from the five most productive countries using VOSviewer version 1.6.20 (Leiden University, The Netherlands). During the generation of the density map, the minimum occurrence threshold was set to two, meaning that only keywords appearing at least twice were included in the visualization. Among the 155 identified keywords, 31 met this criterion and were displayed in the network and density maps. This threshold ensured a balanced representation of frequently co-occurring terms while minimizing visual noise from single-instance keywords.

Türkiye's Contribution to CBCT Research

The overlay visualization of keywords in WoS-indexed CBCT endodontic publications originating from Türkiye illustrates a chronological shift in research focus (Fig. 3). Earlier studies (2013–2018, shown in blue tones) mainly concentrated on anatomical and morphological terms such as "root canal morphology", "canal configuration", and "CBCT accuracy".

In contrast, more recent publications (2020 onwards, indicated in yellow tones) emphasize clinically oriented and technological topics, including "guided endodontics", "three-dimensional imaging", and "root fracture detection".

The subject distribution of CBCT endodontic studies originating from Türkiye within the WoS database is presented in Figure 4.

TR Dizin Database Analysis

Filtering by publication year in the TR Dizin database is available only from 2017 onwards. A search conducted using the same English and Turkish keywords retrieved 61 studies, comprising 44 research articles, 9 case reports, and 8 review articles. The annual distribution of these studies is presented in Table 4, while their distribution across journals is provided in Table 5.

A comparison between WoS and TR Dizin demonstrated that CBCT related endodontic research in both data-

Table 8. Institutional Distribution in TR Dizin

Institution	Count
Foreign Institutions	18
Ankara University	4
Marmara University	3
Republic of Türkiye Ministry of Health	3
İstanbul Medipol University	3

Table 9. City distribution in TR Dizin

City	Count
Ankara	9
İstanbul	9
Aydın	2
Diyarbakır	2
Hatay	2

Table 10. Country Distribution (Collaboration)

Country	Count
Türkiye	17
Germany	1
USA	1
Austria	1
Others	1

Table 11. Author productivity in TR Dizin

Author	Count
Kaan Orhan	5
Ahmed A. Madfa	2
Elham Senan	2
Hatem Alhadainy	2
Gediz Geduk	2

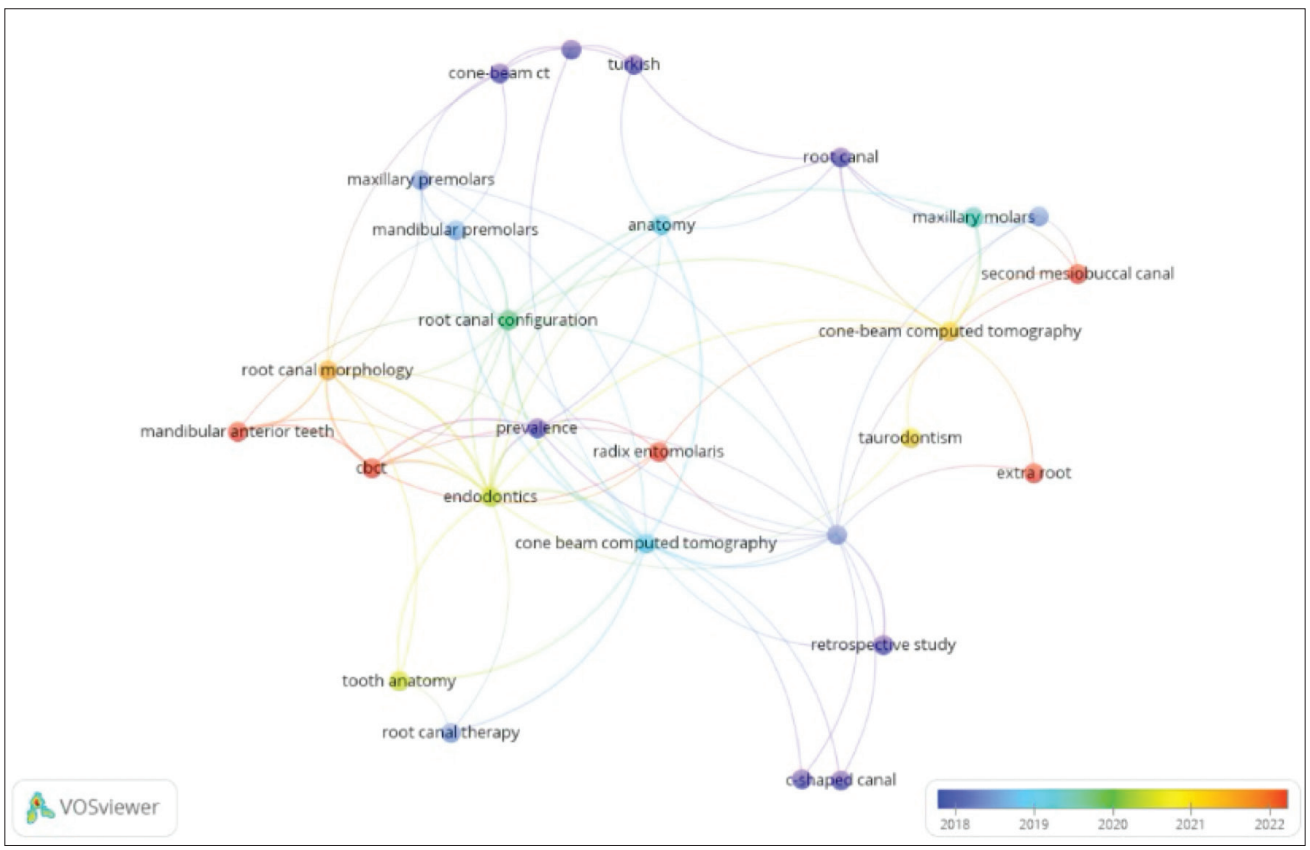

Fig. 3. Keyword network of publications in the WoS database of researchers in Türkiye.

bases covers similar thematic areas (Fig. 5). However, TR Dizin offers broader subject-area classifications rather than standardized article-specific keywords. Therefore, subject headings were used instead of keywords to ensure methodological accuracy and database compatibility.

Analysis of the TR Dizin dataset revealed clear institutional, regional, and authorship patterns. Table 8 presents the institutional distribution, showing that foreign insti-

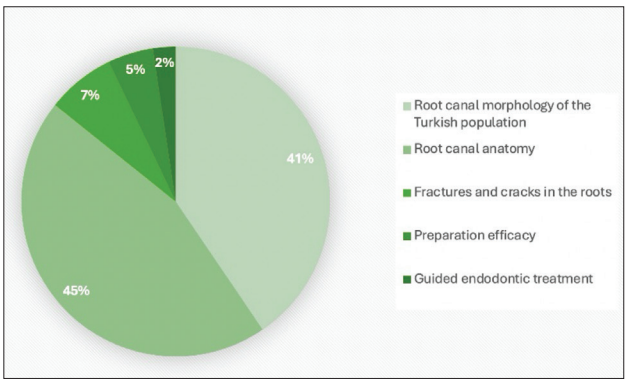

Fig. 4. Subject distribution of studies submitted from Türkiye in the WoS database.

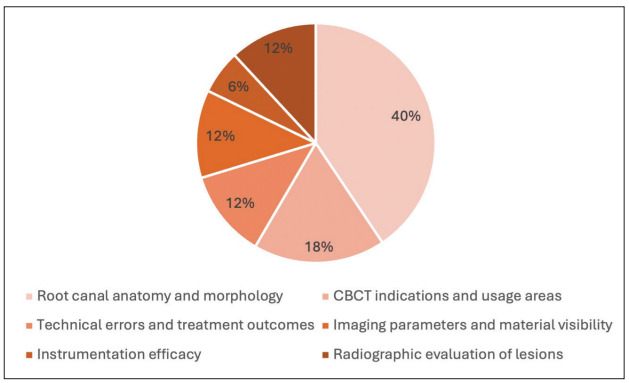

Fig. 5. Subject distribution of publications in TR DİZİN database.

tutions collectively formed the largest category, followed by major state universities and national academic centers. Table 9 outlines the city-level distribution, where Ankara and İstanbul emerged as the principal hubs of scientific output. Collaboration analysis (Table 10) showed that most publications originated from Türkiye, with limited but notable contributions from Germany, the United States, Austria and others.

Regarding authorship productivity (Table 11), Kaan Orhan was identified as the most prolific author in the TR Dizin dataset. Finally, subject-area frequencies (Table 7) confirmed that Dentistry was the dominant subject area, followed by Microscopy and Imaging Science, consistent with the thematic distribution observed in the WoS analysis.

Discussion

This bibliometric analysis aimed to identify research trends in CBCT use in endodontics within the WoS and TR Dizin databases, focusing on study distribution by year, leading countries, and prominent journals.

CBCT has proven to be a valuable diagnostic and treatment planning tool in endodontic practice. However, like all radiological methods, it has limitations, including potential artifacts and exposure to ionizing radiation. Therefore, understanding when CBCT can significantly impact diagnosis and treatment planning versus when it offers little to no additional benefit over conventional imaging is crucial (11).

The literature supports CBCT's role in complex endodontic cases, particularly in endodontic surgery, root canal anatomy assessment, apical periodontitis, vertical root fractures, root and alveolar fractures, and specific types of root resorption, where conventional radiographic techniques may be insufficient (12,13).

Various imaging modalities, including magnification devices, periapical radiographs, and CBCT, have been used to visualize root canal morphology. Among these, CBCT provides three-dimensional reconstructions, allowing for a more detailed evaluation of anatomical complexities (14,15).

Bibliometric analysis is widely used to uncover research trends in endodontics and various other dental specialties. In recent years, such analyses have gained increasing prominence, as they help identify emerging topics and highlight the evolving focus of each field (16-18).

The subject distribution of studies submitted from Türkiye in the WoS database shows that the research orientation is concentrated mainly on morphology and anatomical visualization. Over time, the use of CBCT in endodontics has evolved from visualizing root canal morphology to serving as an integral 3D imaging tool in treatment planning. This shift reflects the broader trend in endodontic research toward incorporating advanced imaging technologies for improved diagnostic accuracy, treatment precision, and clinical decision making (19-21).

The temporal keyword map shows a progressive shift in the research focus of CBCT endodontic studies originating from Türkiye. Earlier work primarily addressed anatomical variations and root canal morphology, whereas recent publications have shifted toward technology oriented applications such as guided endodontic procedures and digital treatment planning. This trend mirrors the global transformation in endodontic imaging research, suggesting that national research priorities are increasingly aligned with international developments.

When evaluated comparatively, the keywords identified in studies from Türkiye show a strong parallel with those of the five most productive countries. This similarity indicates that Türkiye's research trajectory aligns with global scientific trends.

Our analysis revealed that both WoS and TR Dizin datasets include a substantial number of studies focusing on root canal anatomy and morphological variations, consis-

tent with previous literature. The growing emphasis on technology-driven, application-oriented research demonstrates a transition from descriptive imaging studies toward advanced diagnostic and clinical applications.

The numerical results provide further insight into CBCT-related endodontic research activity. WoS data showed an upward trend, with annual publications rising from early single-digit outputs to 45 studies in 2024. TR Dizin displayed a similar concentration of publications between 2020 and 2024. Türkiye's share of 9.7% among SCI-E indexed publications reflects a measurable contribution to the global literature.

Several contextual factors may help explain Türkiye's contribution to the observed increase in CBCT related endodontic publications. Over the past decade, access to CBCT technology has expanded substantially across dental faculties and specialist clinics, facilitating a rise in imaging-based research. In parallel, the number of postgraduate programs and specialist training positions in endodontics has increased, creating a larger pool of researchers who incorporate CBCT into thesis projects and academic studies. Additionally, the strengthening of academic incentive systems, particularly those emphasizing publication in internationally indexed journals, has further encouraged researchers to conduct and publish CBCT focused investigations. Together, these developments may have contributed to the upward trend observed in both WoS and TR Dizin datasets.

Several contextual factors may help explain Türkiye's rising contributions. Increased access to CBCT technology, growth in postgraduate training programs, and academic incentives likely supported the upward trend in both datasets.

Future research may further incorporate citation network analyses, co-authorship mapping, and topic modeling to explore the intellectual and collaborative structures of CBCT endodontic research. Comparative evaluations of national and global trends could also provide deeper insight into Türkiye's growing academic contribution to this field.

In line with the study hypothesis, Türkiye's CBCT related publication trends generally mirror global patterns. Although the overall publication volume remains lower than that of leading countries, the thematic alignment indicates that national research follows international developments.

When WoS and TR Dizin are compared, complementary patterns emerge: WoS reflects global research visibility and standardized indexing, whereas TR Dizin provides granular national-level detail on institutions, regions, and subjects. Together, the databases offer a more comprehensive view of CBCT-related endodontic research.

In addition to quantitative differences, WoS and TR Dizin also exhibit important qualitative distinctions. WoS predominantly indexes internationally oriented journals that publish mainly in English and follow strict visibility and citation standards, as outlined in the Web of Science Journal Selection Criteria. In contrast, TR Dizin functions as a national indexing system designed to support locally produced scientific literature, and many journals within its scope publish primarily in Turkish according to its official evaluation guidelines. These structural differences shape the international dissemination and citation impact of publications, underscoring the importance of bridging national and global publication practices to enhance the visibility of locally produced research.

These findings also align with previous CBCT bibliometric analyses. The Scopus-based study by Karobari et al. (3) reported that global CBCT endodontic research is dominated by countries such as Saudi Arabia, India, China, Brazil, Iran, and the United States, with Türkiye contributing a moderate volume. In our study, Türkiye accounted for 9.7% of SCI-E indexed CBCT publications, consistent with previously reported global patterns.

Limitations

This study is limited to data obtained from the WoS and TR Dizin databases. Although these platforms provide standardized formats for international and national comparisons, publications indexed exclusively in other sources such as Scopus or PubMed were not captured. These databases were intentionally excluded to avoid inconsistencies stemming from differing indexing structures. Additionally, since academic output for 2025 was not yet complete at the time of data collection, only publications up to 2024 were evaluated, and citation counts reflect the retrieval period, which may change with future updates. Another methodological limitation is that TR Dizin does not provide standardized author keywords comparable to WoS; therefore, only general subject categories could be analyzed, limiting the granularity of keyword-based comparisons. Author affiliation data were used as reported in the database exports without manual verification, which may introduce minor inaccuracies in institutional attribution. Finally, duplicate records were removed using Excel-based filtering, and although careful checks were performed, a small risk of metadata-related error remains.

Conclusion

This bibliometric analysis offers a comprehensive overview of both global and national research trends concerning CBCT use in endodontics. The results demonstrate thematic overlap between international and national data-

bases and underscore Türkiye's increasing contribution to this field. These findings can inform future research priorities and facilitate further studies on endodontic imaging and CBCT applications.

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ORIGINAL ARTICLE

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Efficacy of Reciprocating and Rotary Nickel-Titanium Files on Bacterial Reduction in Enterococcus Faecalis-Infected Root Canals: An Ex-Vivo Study

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Purpose: This study aimed to evaluate the effectiveness of rotary VDW.ROTATE (ROTATE), HyFlex EDM (HEDM), and reciprocating Reciproc Blue (RPCB) nickel–titanium file systems in reducing bacterial load in root canals infected with *Enterococcus faecalis (E. faecalis)*.

Methods: Thirty-four mandibular premolar teeth canals were contaminated with *E. faecalis* for four weeks and prepared using file systems (ROTATE, HEDM, or RPCB; n=10). Four uncontaminated teeth served as a negative control. Bacterial load was quantified via the plate culture method. Scanning electron microscopy (SEM) was used to assess the impact of preparation on biofilm. Bacterial reduction was calculated, and data were analyzed using one-way ANOVA at a 5% significance level.

Results: Before preparation, all contaminated samples exhibited bacterial growth with an average bacterial load of 7.26 log CFU. All file systems reduced intracanal bacterial load ($p<0.05$), with no significant differences between systems ($p>0.05$). SEM images revealed disrupted biofilm-like structures in all groups, but bacteria were not completely eliminated in any canal section. Apical sections exhibited more smear layer than coronal sections.

Conclusion: Microbiological analysis and SEM images confirmed that none of the tested file systems completely eliminated *E. faecalis* from root canals. No significant differences in bacterial reduction were observed among the file systems.

Keywords: Bacterial reduction; Enterococcus faecalis; HyFlex EDM; Reciproc Blue; VDW.ROTATE.

Introduction

The primary goal of endodontic treatment is to eliminate bacterial byproducts, which play a critical role in the pathogenesis of pulpal and periapical diseases (1). However, certain microorganisms, such as *Enterococcus faecalis* (*E. faecalis*), a gram-positive facultative anaerobic bacterium,

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can persist within the root canal system even after chemomechanical preparation, leading to recurrent or persistent infections (2,3). The ability of *E. faecalis* to form biofilms, penetrate dentinal tubules, and survive under high pH and nutrient-deprived conditions contributes to its resistance to conventional endodontic procedures (2,4).

Mechanical preparation is a crucial step in endodontic treatment for reducing intracanal bacterial load (3). The effectiveness of bacterial elimination may be influenced not only by irrigation protocols but also by the kinematics, alloy properties, and design of the instrumentation systems, which can affect debris removal and biofilm disruption within the root canal system. Rotary file systems operating with continuous rotational motion have been widely used and reported to reduce bacterial and endotoxin loads by more than 90% (3,4). However, these systems often require multiple instruments, increased working time, and greater technical sensitivity (3). Previous studies have demonstrated that reciprocating single-file systems can achieve bacterial reduction comparable to that of multifile rotary systems, suggesting that factors such as instrument kinematics and mechanical interaction with dentine may play a critical role in intracanal bacterial reduction rather than working time alone (3).

VDW.ROTATE (ROTATE; VDW, Munich, Germany) is a nickel–titanium (NiTi) rotary file system consisting of three instruments designed for narrow or wide canals. These files feature an S-shaped cross-section, an off-centered design, and a constant taper, which may contribute to efficient canal shaping and debris removal (5).

In contrast, single-file systems such as Reciproc Blue (RPCB; VDW, Munich, Germany) and HyFlex EDM (HEDM; Coltene/Whaledent, Altstätten, Switzerland) have been developed to simplify instrumentation protocols and reduce preparation time (4). Beyond time efficiency, differences in motion dynamics and metallurgical properties may influence their interaction with intracanal biofilms. RPCB files operate in reciprocating motion and are manufactured using a proprietary thermal treatment, resulting in a blue titanium oxide surface layer that enhances flexibility and resistance to cyclic fatigue compared with conventional Reciproc files (6–8). HEDM is a single-file system produced from controlled-memory (CM) NiTi alloy using electrical discharge machining (EDM), a process that modifies the surface and internal structure of the alloy to improve flexibility. The file exhibits variable cross-sectional designs along its length, including a quadratic apical section, a trapezoidal middle section, and a triangular coronal section (9,10).

Despite the widespread use of these systems, no studies have directly compared the bacterial reduction efficacy of VDW.ROTATE, RPCB, and HEDM file systems in *E. faecalis*–infected root canals. This study aimed to quantitatively evaluate their bacterial reduction efficiencies in *E. faecalis*-contaminated root canals. The null hypothesis was that there would be no difference in bacterial reduction efficacy among the tested file systems.

Materials and Methods

Sample Size Determination

Based on a previous study (3), a power calculation was performed using a chi-square test and variance statistical test (G*Power 3.1; Heinrich Heine University, Düsseldorf, Germany) with α=0.05 and β=0.95, indicating a minimum sample size of eight teeth per group.

Sample Selection

Following approval from the local ethics committee (No: 2019/279), 34 non-carious, single-rooted, single-canal mandibular premolar teeth extracted for orthodontic or periodontal reasons were selected. The study was conducted in accordance with the principles of the Declaration of Helsinki. Debris and soft tissue were removed using periodontal curettes. Preoperative radiographs in mesiodistal and buccolingual directions confirmed oval-shaped canals (11). Teeth with two canals, calcifications, resorption, cracks, or root curvature greater than 10° were excluded. Teeth were examined under a stereomicroscope for cracks, and those with cracks or apices wider than a size 15 K-file were replaced. Teeth were stored in 0.9% saline until use.

Crowns were removed under water cooling, and root lengths were standardized to 16±1 mm. Working lengths were set 1 mm short of the apical foramen. Root canals were treated in an ultrasonic bath with 17% ethylenediaminetetraacetic acid (EDTA;Wizard, Rehber Kimya San. Tic. Aş., Istanbul, Türkiye) and 6% sodium hypochlorite (NaOCl; Coltene/Whaledent) for 10 minutes to open dentin tubules and remove the smear layer. Residual EDTA and NaOCl were neutralized with phosphate-buffered saline and distilled water. Root apices were sealed with composite resin (3M ESPE Z250, Saint Paul, MN), and external root surfaces were coated with nail polish. Each tooth was placed in 1.5 mL Eppendorf tubes with brain heart infusion (BHI) broth (Difco Laboratories, Detroit, MI, USA) and sterilized at 121°C and 15 psi for 15 minutes. Four randomly selected teeth were left uncontaminated as a negative control, with sterility confirmed by scanning electron microscopy (SEM) (Fig. 1).

Contamination with *E. faecalis*

A single colony of *E. faecalis* (ATCC 29212) from a cul-

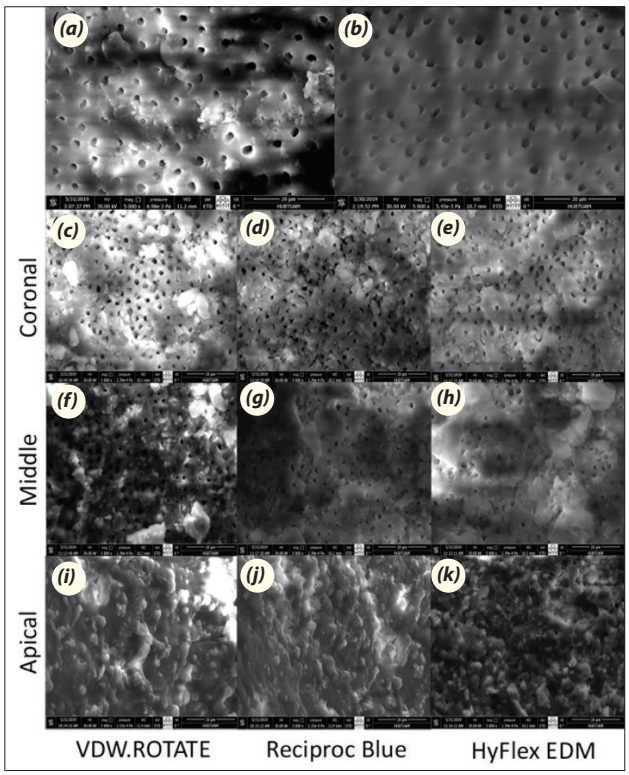

Fig. 1. Representative scanning electron microscopy images of the selected samples from different groups: **(a)** positive control; **(b)** negative control; **(c)**, **(f)**, and **(i)** for VDW.ROTATE group; **(d)**, **(g)**, and **(j)** for Reciproc Blue group; **(e)**, **(h)**, and **(k)** for HyFlex EDM group from the coronal to the apical root levels. Biofilm-like structures with thick and dense debris were removed substantially from the apical to the coronal root levels for each preparation group.

ture maintained at 4°C was inoculated into 50 mL of BHI medium with 0.25% glucose and incubated at 37°C for 24 hours. Root canals of 34 teeth were inoculated with a bacterial culture adjusted to McFarland turbidity standard 1 (3 × 108 cells/mL) and mixed with 5 mL of sterilized BHI. The mixture was introduced into the canals using a sterile 1–10 µL pipette tip. This process was repeated every 48 hours with fresh 24-hour cultures for four weeks at 37°C in a 95% humid environment. Ten teeth were randomly assigned to a positive control group, and contamination was confirmed by SEM (Quanta 450 FEG; FEI Ltd., Brno, Czech Republic) (Fig. 1). All procedures were conducted under aseptic conditions.

Root Canal Preparation

Contaminated teeth were randomly divided into three groups (n=10) and prepared as follows:

VDW.ROTATE Group

Canals were prepared using VDW.ROTATE files (sizes 15/.04, 20/.05, and 25/.06) with a VDW GOLD Reciproc endodontic motor (VDW) at manufacturer-recommended settings (300 rpm; torque: 1.3 Ncm for size 15/.04, 2.1 Ncm for size 20/.05, 2.3 Ncm for size 25/.06). Files were used with 2–3 mm in-out pecking motions and slight apical pressure. After three in-out motions, files were removed, cleaned with gauze, and reinserted. This process was repeated at least twice until the working length was reached.

RPCB Group

Canals were prepared using RPCB R25 (size 25/.08) files with the VDW GOLD Reciproc motor in RECIPROC ALL mode. Files were used with 2–3 mm in-out pecking motions and slight apical pressure, cleaned with gauze after three motions, and reinserted until the working length was reached.

HEDM Group

Canals were prepared using HEDM (size 25/.08) files with the VDW GOLD Reciproc motor in continuous rotation at 500 rpm and 2.5 Ncm, as recommended. Files were used with 2–3 mm in-out pecking motions, cleaned with gauze after three motions, and reinserted until the working length was reached.

For all groups, 10 mL of sterile saline was used per canal (5 mL during preparation, 5 mL post-preparation) with a 31-gauge endodontic needle (NaviTip; Ultradent Products, South Jordan, UT, USA) positioned 2 mm from the working length. Irrigation was repeated after each file change (VDW.ROTATE) or file removal (RPCB, HEDM). A new file set was used for each canal. All procedures were performed aseptically in a sterile cabinet by an experienced endodontist.

Bacteriological samples were collected before (S1) and after (S2) preparation. For S1, canals were irrigated with 1 mL of sterile saline for 30 seconds, and two sterile size 15 paper points were held in the canal for 1 minute. For S2, samples were collected using two sterile size 25 paper points ethylenediaminetetraacetic acid as described for S1. Paper points were stored in 1 mL Tris-EDTA buffer at –20°C.

Quantification of Bacterial Load

Samples were homogenized for 1 minute, serially diluted, and plated in triplicate on m-Enterococcus agar (Difco, Le Pont de Claix, France). Plates were incubated at 37°C for 48 hours, and colony-forming units per milliliter (CFU/mL) were visually assessed.

Table 1. Bacterial reduction after instrumentation (mean and standard deviation of log10 CFU mL_1)

	Reduction Mean ±SD	Reduction percentage mean ± SD (%)
RPCB	3.49±1.10	44±11
HEDM	2.86±0.87	40±12
VDW.Rotate	2.70±0.87	36±11
p value	0.67	0.174

SEM Analysis

The effect of the preparation process on bacteria adherent to the root canal walls and the presence of bacteria within the dentinal tubules were examined under scanning electron microscopy (SEM). Five teeth per group were fixed in 10% buffered formalin for one week. Longitudinal grooves were prepared on the buccal and palatal surfaces using a diamond bur, and the roots were split with a chisel. The specimens were dehydrated in ascending concentrations of ethanol (70%, 95%, and 100%), critical-point dried, and sputter-coated with gold–palladium. Coronal, middle, and apical thirds were examined under SEM at 5,000× magnification to evaluate surface-associated bacterial presence and dentinal tubule penetration.

Statistical Analysis

Bacterial load data were converted to log10 for analysis. Normality and variance equality were assessed using the Shapiro-Wilk test. Intragroup comparisons of pre- and post-preparation bacterial loads were analyzed using paired t-tests. One-way ANOVA was used to compare mean bacterial reduction and percentage reduction between groups with SPSS 21 (SPSS Inc., Chicago, IL, USA) ($p<0.05$).

Results

No bacterial growth was observed in the negative control samples (Fig. 1). Pre-preparation samples had an average bacterial load of 7.26 log CFU. All groups showed significant bacterial load reduction post-preparation ($p<0.05$) (Fig. 2), with no significant differences in mean or percentage bacterial reduction among the file systems (Table 1) ($p>0.05$).

SEM images of unprepared, *E. faecalis*-contaminated canals showed biofilm-like structures with an extracellular polymeric matrix along the dentin surface (Fig. 1). Post-instrumentation, biofilm-like structures were disrupted in all groups. Thick, dense debris was observed in all sections, particularly in the apical third, occluding dentinal tubules. Coronal and middle sections showed less debris and biofilm than apical sections in all groups.

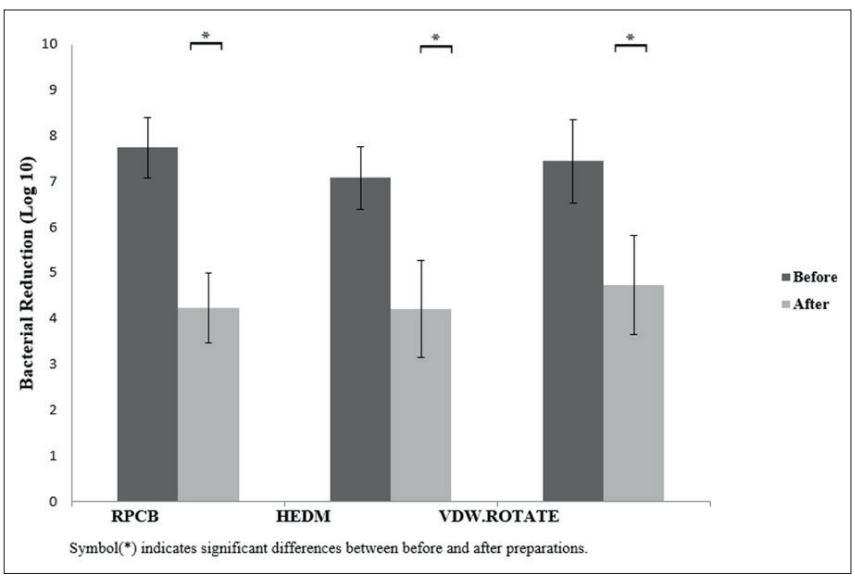

Fig. 2. Distribution of the mean percentage values of bacterial reduction in each group after root canal instrumentation.

Discussion

The aim of this study was to investigate the bacterial reduction effects of VDW.ROTATE, RPCB, and HEDM NiTi file systems on root canals contaminated with *E. faecalis*. The present study demonstrated that all tested instrumentation systems significantly reduced intracanal bacterial load; however, no statistically significant differences were observed among the groups, consistent with previous ex vivo and clinical studies comparing rotary and reciprocating instrumentation systems (3,12-16). Therefore, the null hypothesis of the study was accepted.

The lack of significant differences among the tested systems may be attributed to the standardized preparation protocols used in the present study, including similar apical preparation sizes and irrigation conditions. Under such controlled conditions, the mechanical action of different NiTi instruments appears to result in comparable reductions in planktonic intracanal bacteria, suggesting that differences in kinematics or instrument design alone may not be decisive for bacterial reduction within the canal lumen (3,4,15,16).

The complex anatomy of the root canal system, including isthmuses, ramifications, and lateral canals, presents challenges for complete bacterial elimination and microbiological sampling (12). The use of single-rooted, oval-shaped mandibular premolars in the present study was intended to provide a standardized yet challenging canal morphology, which may partially explain the persistence of bacteria after instrumentation (17).

The use of *E. faecalis* as the test microorganism is consistent with previous studies, as it is frequently isolated from persistent endodontic infections and exhibits resistance to intracanal antimicrobial procedures (13,18,19). Its ability to survive under adverse environmental conditions makes it a suitable model organism for evaluating bacterial reduction following chemomechanical preparation (1,11).

Sterile distilled water was used as the irrigant to eliminate the confounding antimicrobial effects of chemical solutions and to isolate the mechanical contribution of the instrumentation systems to bacterial reduction, as reported in similar in vitro studies (13,20,21). However, this methodological choice limits direct extrapolation of the findings to clinical practice, where sodium hypochlorite irrigation plays a crucial role in bacterial elimination (14,22,23).

Various methodologies have been employed to evaluate bacterial reduction following endodontic instrumentation, including SEM, molecular techniques, histochemical analyses, and plate-culture methods (22,24,25). In the present study, the plate-culture method combined with paper-point sampling was used to quantify intracanal bacterial load. This approach detects only cultivable bacteria present in the canal lumen at the time of sampling, and does not account for bacteria in a viable but non-culturable (VBNC) state, which may lead to an underestimation of the actual bacterial presence (26-28). Therefore, the bacterial reduction observed in this study should be interpreted as a reduction in cultivable planktonic bacteria rather than complete bacterial elimination.

Consistent with the results of many in vivo and in vitro studies, all file systems tested in this study caused a significant reduction in intracanal bacterial load compared with the initial load (3,13-15,29-30). However, none of the tested systems achieved complete bacterial elimination, a finding also reported by Machado et al. (16) and other authors using plate-culture and SEM-based evaluations (21,24).

In the present study, no difference was found between RPCB and HEDM single-file systems with different kinematics. This finding supports previous reports indicating that instrumentation kinematics alone may not significantly influence bacterial reduction when comparable preparation sizes are achieved (4,12,14,15). Similarly, no difference was found between the single-file systems (RPCB and HEDM) and the multi-file rotary system (VDW.ROTATE), in agreement with clinical and ex vivo studies reporting comparable antibacterial effectiveness between single-file and multi-file NiTi systems (3,12,14,16).

Although some studies have reported differences in smear layer removal between reciprocating and rotary systems, such findings may not directly correlate with bacterial reduction, as smear layer removal and planktonic bacterial elimination represent distinct outcomes (31). Variations in file design, irrigant type, and evaluation methods may contribute to the heterogeneity of results reported in the literature.

The limitations of the present study include its in vitro design, the use of a single bacterial species, and reliance on plate-culture methods combined with paper-point sampling (21,25-27). In addition, although the sample size was determined by a priori power analysis, subtle differences among instrumentation systems may require larger sample sizes or alternative detection methods to be identified.

Within the limitations of this in vitro study, the findings suggest that contemporary rotary and reciprocating NiTi systems achieve comparable reductions in intracanal bacterial load. Clinically, instrument selection may therefore be guided by canal anatomy, operator experience, and procedural efficiency rather than expectations of superior antibacterial performance from a specific instrumentation system (14,15).

Conclusion

No differences in the bacterial reduction efficiency were found between the VDW.ROTATE, RPCB, and HEDM NiTi files in *E. faecalis*–contaminated root canals. Moreover, none of the tested file systems completely eliminated intracanal bacteria.

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Ethical Approval: The study protocol was approved by the Ankara Yıldırım Beyazıt University Ethics Commitee (date: 31.07.2019 protocol no: 2019-279).

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

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ORIGINAL ARTICLE

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Fracture Resistance of Immature Teeth Filled with Biodentine and BIOfactor MTA: An in Vitro Study

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Purpose: This study aimed to evaluate and compare the fracture resistance of simulated immature teeth filled with Biodentine (Septodont, St-Maur-des-Fossés, France) and BIOfactor MTA (Imicryl Dental, Konya, Türkiye) used as apical plugs.

Methods: In this study, 74 single-rooted mandibular premolars with root lengths standardized to 10±1mm were used. The teeth were divided into two main experimental groups—Biodentine and BIOfactor MTA (n=30)—and two control groups (n=7). The Biodentine and BIOfactor MTA groups were further divided into two subgroups according to apical plug thickness. In one subgroup, a 4 mm apical plug was placed, while in the other, the canals were completely filled with Biodentine or BIOfactor MTA. In the negative control group, root canals were prepared retrogradely without creating an access cavity. In the positive control group, canals were instrumented after access cavity preparation but left unfilled. Each specimen was subjected to a fracture resistance test using a universal testing machine, and the maximum force required to cause fracture was recorded in Newtons (N). Data were analyzed using the One-Way ANOVA test.

Results: The negative control group exhibited the highest fracture resistance compared to all other groups ($p<0.05$). No significant difference was observed between the 4 mm apical plug and full canal filling subgroups for either Biodentine or BIOfactor MTA ($p>0.05$). The highest fracture resistance was found in the negative control group.

Conclusion: BIOfactor MTA showed similar fracture resistance to Biodentine. Apical plug thickness did not significantly influence the fracture resistance of immature teeth.

Keywords: Apical plug; biodentine; BIOfactor MTA; fracture resistance; immature teeth.

Introduction

Traumatic dental injuries are most commonly observed in children and adolescents, often resulting in pulp necrosis and arrest of root development (1). Arrested root development leads to open apical foramina and thin dentinal walls, making the management of such cases challenging from both endodontic and restorative perspectives. Moreover, this condition increases the susceptibility of teeth to root fractures due to the weakened dentin structure (2). Apexification treatment has been considered one of the best therapeutic options for such immature teeth. Over the years, various materials have been proposed for apexi-

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fication of immature teeth. Calcium hydroxide is one of the materials used in apexification treatment due to its high pH level and antimicrobial activity (3).

The success rate of long-term apexification using calcium hydroxide has been reported to range between 79% and 96%. However, major disadvantages such as the unpredictability of apical barrier formation time, increased tooth fragility, and a higher risk of root fracture have been reported in the literature (4,5). To overcome these disadvantages, various calcium silicate-based materials with superior properties such as osteogenic potential, sealing ability, and antibacterial activity have been used for single-visit apexification treatment. (6). Mineral Trioxide Aggregate (MTA), a calcium silicate-based material, has been considered the gold standard for apical barrier formation in immature teeth (7). Furthermore, several studies have shown that forming an apical barrier with MTA in immature teeth can enhance resistance to both horizontal and vertical root fractures (8,9).

In immature permanent teeth, incomplete root development leads to an open apex and increases the risk of fracture due to the presence of thin dentinal walls. Therefore, treatment protocols for immature teeth should aim not only to control infection but also to enhance fracture resistance. In this context, fracture resistance tests serve as an important method to evaluate the extent to which these materials can support the structurally weakened dentin. In vitro studies on fracture resistance have provided scientific evidence for material selection in clinical practice by comparing the mechanical performance of different filling materials (2,4). In this context, calcium silicate–based bioactive materials such as Biodentine and BIOfactor MTA have gained attention due to their biocompatibility and their potential to mechanically reinforce root dentin by interacting with the dentin structure, thereby contributing to improved fracture resistance in immature teeth.

Biodentine is a calcium silicate-based material that was introduced to the market as a bioactive dentin substitute. It possesses compressive strength, elastic modulus, and microhardness properties similar to those of natural human dentin. Biodentine is a stable, non-resorbable, and hydrophilic material that can be easily applied into the root canal. Additionally, it has a rapid setting time of approximately 12 minutes. Thanks to its enhanced physical, mechanical and biological properties, Biodentine has demonstrated a significant advantage over other materials in the treatment of immature teeth (7,9).

BIOfactor MTA is a Türkiye-origin, calcium silicate–based bioactive root repair material. According to the manufacturer, its powder component consists of tricalcium silicate, dicalcium silicate, tricalcium aluminate, and ytterbium oxide as a radiopacifying agent, while the liquid component contains 0.5–3% water-soluble carboxylated polymer and demineralized water. The gel-form liquid facilitates handling and placement within the root canal and allows the material to be prepared in either a thick or flowable consistency, depending on the clinical indication. When mixed to a thick or putty-like consistency, BIOfactor MTA can be used for direct pulp capping, perforation repair, root-end filling, and pulpotomy procedures. When prepared in a flowable consistency, it is suitable for the repair of resorption defects, apexification treatment, and use as an apical plug material. The fine powder structure of BIOfactor MTA is reported to contribute to a shortened setting time, and the material offers advantages such as high sealing ability, high radiopacity, biocompatibility, and ease of handling (10-12).

BIOfactor MTA (Imicryl Dental, Konya, Türkiye) and Biodentine (Septodont, St-Maur-des-Fossés, France) have been introduced to the market for various applications, including direct pulp capping, pulpotomy, apexification, root-end filling, apical plug formation, and perforation repair. While there are numerous in vitro studies conducted with Biodentine (2,10), there are very few studies in the literature regarding BIOfactor MTA. These studies have examined the characteristics of the material–dentin interface (10), the push-out bond strength of BIOfactor MTA (11) and its radiopacity (12).

In the literature, there is no in vitro study evaluating the effect of apical plug thickness using Biodentine and BIOfactor MTA on the fracture resistance of immature teeth. The aim of this study is to evaluate the effect of BIOfactor MTA and Biodentine, applied either as a 4 mm apical plug or as full canal obturation, on the fracture resistance of simulated immature teeth. The null hypothesis of this study is that Biodentine and BIOfactor MTA exhibit similar fracture resistance in simulated immature permanent teeth, and that there is no statistically significant difference in fracture resistance between the apical plug and full canal filling applications.

Materials and Methods

Ethical Approval and Sample Size Calculation

This study was approved by the Human Ethics Committee of the Institutional Review Board (protocol No. 2020/06) and conducted according to Declaration of Helsinki. Based on a previously conducted study (4), the sample size was determined using an ANOVA: Fixed effects, omnibus, one-way test (G*Power 3.1; Heinrich Heine University, Düsseldorf, Germany). The analysis was performed with an alpha level of 0.05, a power of 0.95, and an effect size of

0.54, resulting in an estimated total of 74 teeth being sufficient for the study.

Selection and Preparation of Teeth

In this study, a total of 74 permanent single-rooted and single-canaled mandibular premolar teeth, extracted for orthodontic and periodontal reasons, were used to evaluate the effect of different calcium silicate-based repair materials on the fracture resistance of immature teeth. The teeth were disinfected with 2.5% sodium hypochlorite (NaOCl) solution and stored in distilled water. Periapical radiographs were taken in both buccolingual and mesiodistal directions to evaluate the presence of calcification, internal resorption, or additional root canals. Teeth found to have caries, calcified canals, root resorption, fractures, or cracks on radiographic examination were excluded from the study. To standardize the samples, the mesiodistal and buccolingual diameters at the cementoenamel junction (CEJ) were measured using a digital caliper, and teeth exhibiting marked morphological differences were excluded from the study. Each tooth root was standardized by sectioning with a low-speed diamond bur to obtain a root length of 10±1 mm, measured from the apex to the CEJ. Then, an endodontic access cavity was prepared in each tooth included in the study. A #15 K-type stainless steel hand file was inserted into the root canals to check the canal patency. Teeth with straight, single canals that could be negotiated to the apex were included in the study. Teeth with multiple canals, calcified canals, or previous root canal treatment were excluded. In all groups, the canals were instrumented with size 1 to size 6 Peeso Reamers (Dentsply Maillefer) to simulate immature teeth. During each Peeso Reamer change, the canals were irrigated with 2 ml of 5% NaOCl using a 27-gauge needle syringe. After completion of the enlargement, final irrigation was performed with 5 ml of 5% NaOCl, 5 ml of 17% EDTA, and 5 ml of saline solution. The root canals were dried with paper points and assigned to the experimental groups.

Experimental Groups

The teeth were randomly divided according to the material used into two main experimental groups (n=30) and two control groups (n=7). Each of the two main experimental groups was further divided into two subgroups based on the thickness of the apical plug. In one subgroup, a 4-mm apical plug was placed (n=15), while in the other subgroup, the entire canal was filled with the material (n=15). The apical plug thickness was standardized at 4 mm, as previous studies have reported that apical plugs with a thickness of at least 3–4 mm provide adequate apical sealing ability and favorable mechanical resistance in immature teeth (4). The control groups were separated into a positive control group (n=7) and a negative control group (n=7) (Table 1).

In the negative control group, without preparing any access cavity, the canal spaces were enlarged retrogradely (from apical to coronal) using Peeso Reamers from sizes 1 to 6 in order to simulate immature teeth (Fig.1). In the positive control group, an endodontic access cavity was prepared, and the canal spaces were enlarged from coronal to apical direction using Peeso Reamers from sizes 1 to 6 to simulate immature teeth. No repair material was placed, and the canals were left empty (Fig. 1).

In the BIOfactor MTA (4 mm plug) and Biodentine (4 mm plug) groups, 15 teeth each were filled with BIOfactor MTA and Biodentine, respectively, using a plugger (Dentsply Sirona, Germany) to place a 4 mm thick apical plug into the immature root (Fig. 1). Before completing the obturation with the warm vertical compaction technique, the teeth were incubated in a humid environment at 37°C with 100% humidity for 3 hours. After comple-

Table 1. Endodontic study groups table

Group	Sample Size (n)	Description
Negative Control Group	7	Access cavity (-) Retrograde Preparation (+) Obturation (-)
Positive Control Group	7	Access cavity (+) Ortograde Preparation (+) Obturation (-)
BIOfactor MTA (4 mm Plug)	15	Apical Plug (4mm) Warm Vertical Compaction (+)
BIOfactor MTA (Full obturation)	15	Full Canal Obturation with MTA
Biodentine (4 mm Plug)	15	Apical Plug (4mm) Warm Vertical Compaction (+)
Biodentine (Full obturation)	15	Full Canal Obturation with Biodentine

n: Number of samples.

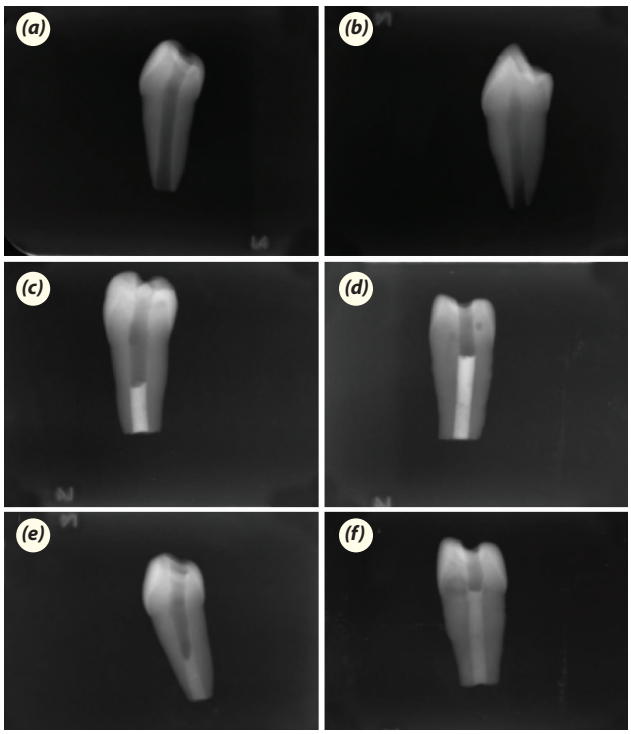

Fig. 1. Periapical radiographs of the experimental groups. Positive Control Group **(a)**, Negative Control Group **(b)**, BIOfactor MTA (4mm plug) **(c)**, BIOfactor MTA (full obturation) **(d)**, Biodentine (4mm plug) **(e)**, Biodentine (full obturation) **(f)**.

tion of the apical plug procedure, the root canal sealer (AH Plus, Dentsply DeTrey, Konstanz, Germany) was mixed according to the manufacturer's instructions. A size 30 lentulo spiral (Maillefer, Ballaigues, Switzerland) was adjusted to 4 mm short of the working length, and the sealer was evenly applied to the canal walls. Warm vertical compaction was performed using a heat source (Eighteeth Fast-Fill, Changzhou, China) set at 200°C. At this stage, gutta-percha was heated and softened and injected into the root canal in 2-mm-thick increments. The placed gutta-percha was compacted using a green-coded stainless steel plugger (Dentsply Sirona, Germany) appropriate to the canal diameter and working length. Intermittent control radiographs were taken during the procedure to evaluate the quality of the obturation. The root canal filling was terminated at the cementoenamel junction (CEJ). Throughout all procedures, care was taken to prevent displacement of the apical plug. Final restorations were then completed using composite resin (Imicryl Dental, Konya, Türkiye).

In the BIOfactor MTA (full obturation) and Biodentine (full obturation) groups, 15 teeth each were completely filled with BIOfactor MTA and Biodentine up to the CEJ (Fig. 1). Before performing the final restoration, the teeth were incubated at 37°C in a 100% humid environment for 3 hours. Final restorations were then completed using composite resin.

Before being subjected to the fracture resistance test, all experimental groups were stored in an incubator at 37°C with 100% humidity for one week to ensure complete setting of the repair materials.

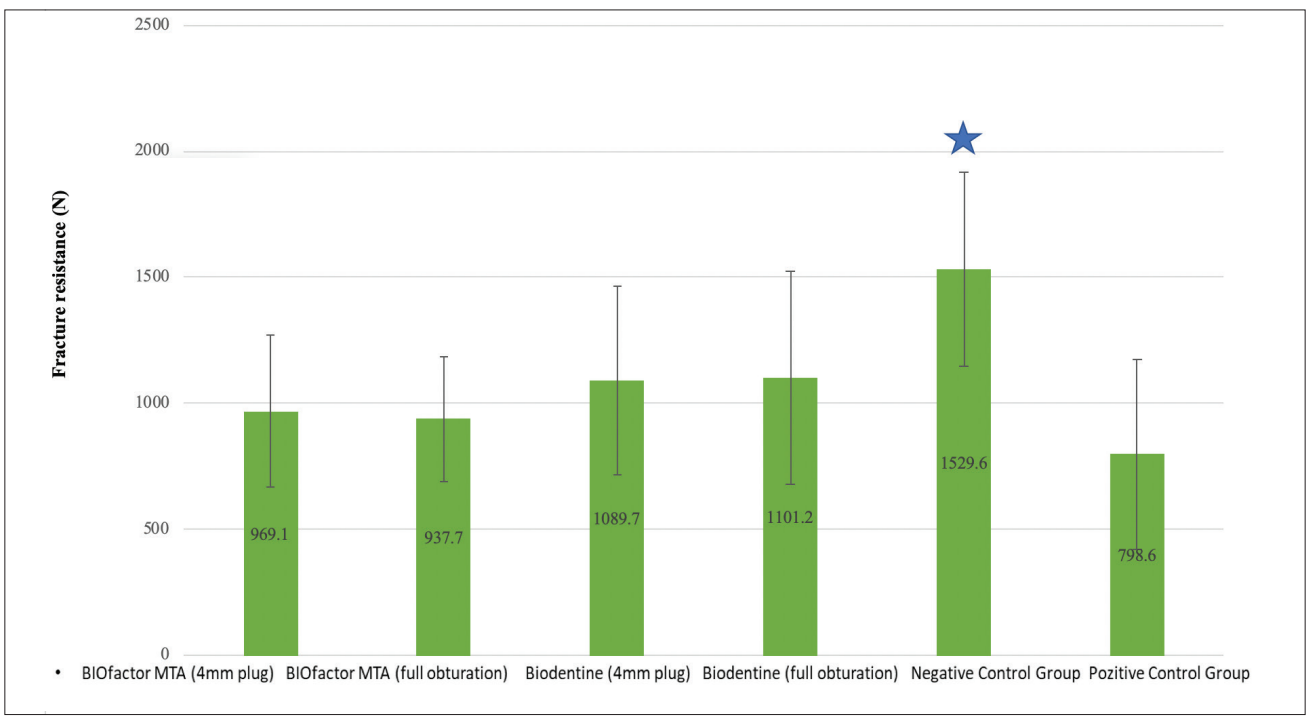

Fig. 3. Fracture resistance values (±SD). ★: The highest fracture resistance value ($p<0.05$).

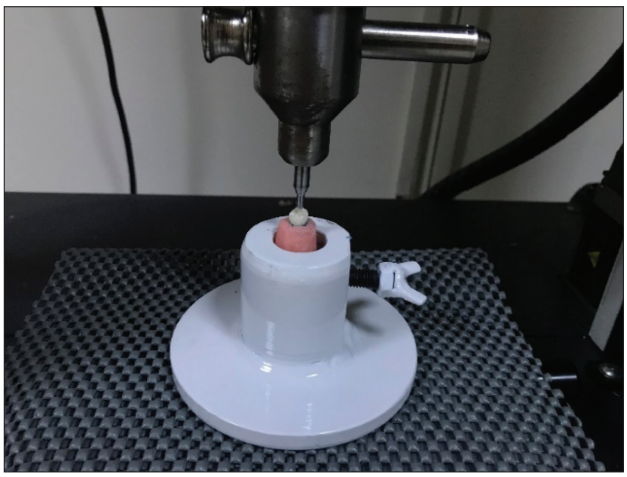

Fig. 2. The universal testing machine.

Periodontal Ligament Simulation

To simulate the periodontal ligament space, each tooth root was immersed into warm wax starting 1 mm below the CEJ until a wax thickness of 0.3 mm was achieved. Once the desired thickness was obtained, the teeth were vertically embedded into self-curing acrylic resin blocks, with 9 mm of the root remaining in the resin, positioned 1 mm below the CEJ to simulate biological width. The wax was then melted to create a 0.3 mm thick negative space between the root surface and the acrylic resin block. This space was then filled with a light-body condensation type silicone impression material (BONASIL Light; DMP Dental Industry SA, Markopoulo Industrial Zone, Greece), starting 1 mm below the CEJ and covering the entire root surface, to simulate the periodontal ligament.

Fracture Resistance Testing

The fracture resistance test was performed using a universal testing machine (Besmak, Ankara, Türkiye) at a loading speed of 0.5 mm/min. A stainless-steel tip (tip diameter =3 mm) was positioned perpendicular to the long axis of the tooth, and a vertical force was applied at a rate of 0.5 mm/min until fracture occurred (Fig. 2). The maximum force required to fracture each tooth was recorded in Newtons (N) and documented in a Microsoft Excel (Microsoft Corporation, Redmond, Washington, USA) file.

Statistical Analysis

The normality of the distribution was assessed. According to the results, the Shapiro Wilk tests yielded a p-value of 0.090, which is above 0.05, indicating that the distribution was considered normal. Therefore, parametric tests were used for statistical analysis. One-way ANOVA was employed to analyze the data within the scope of the study. Mode of fractures compared by groups with Fisher exact test. Upon identifying a statistically significant difference between the groups, Bonferroni post-hoc test was used for detailed group comparisons.

Results

According to the results of the study, the negative control group (1529.6±385.3 N) exhibited the highest mean fracture resistance and showed a statistically significant higher resistance compared to all experimental groups ($p<0.05$). In contrast, the positive control group (798.6±377.0 N) demonstrated the lowest mean fracture resistance value. Additionally, the fracture resistance of the positive control group was found to be significantly lower than that of the negative control group ($p<0.05$) (Table 2) (Fig. 3).

A statistically significant difference was found among the six groups compared in the study in terms of fracture resistance ($F=3.940$, $p<0.05$). In order to determine which groups caused the intergroup differences, a Bonferroni post-hoc test was performed. Following the one-way ANOVA, Bonferroni post hoc comparisons revealed no

Table 2. Mean fracture resistance values of the simulated immature teeth (±SD)

	n	Mean	Std. Deviation	Min	Max	F	df	p
BIOfactor MTA (4mm plug)[a]	15	969.1	301	553.4	1815.1			
BIOfactor MTA (full obturation)[a]	15	937.7	246.1	510	1461.3	3.940	5	0.003*
Biodentine (4mm plug)[a]	15	1089.7	373.8	421.3	2024.4			
Biodentine (full obturation)[a]	15	1101.2	420.8	370.9	1815.5			
Negative Control Group[b]	7	1529.6	385.3	1069.7	2044.3			
Positive Control Group[a]	7	798.6	377	291.4	1256.7			
Total	74	1050.9	382.8	291.4	2044.3			

n: Number of samples; Mean: Mean value; Sd: Standard deviation; Min.: Minimum; Max.: Maximum; F: Anova value; df: degrees of freedom; p: Significance. Statistically significant differences ($p<0.05$) are indicated by different superscript lowercase letters.

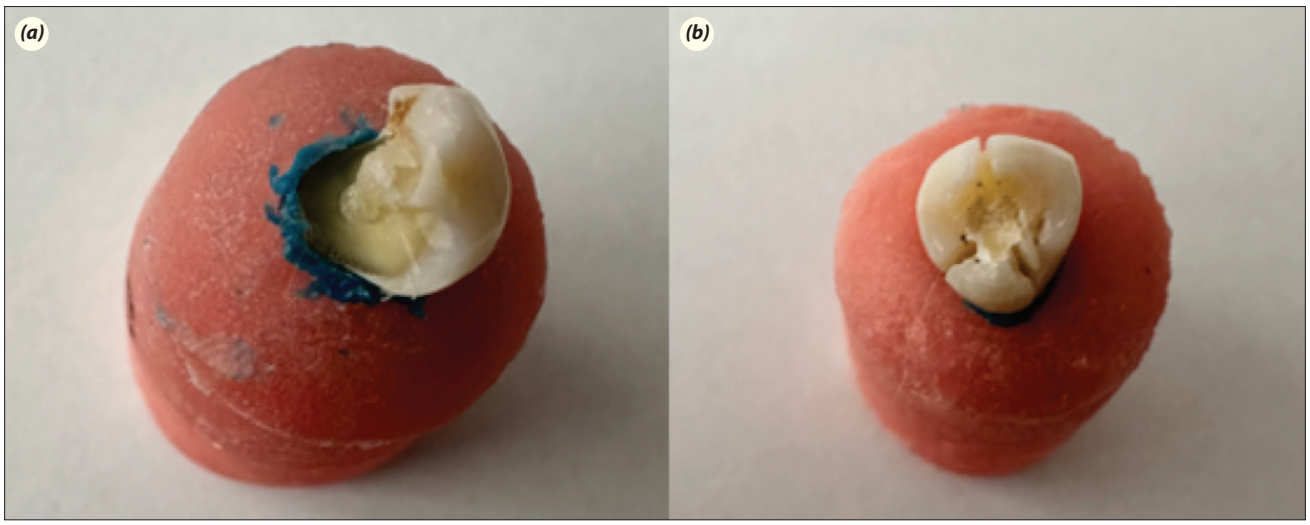

Fig. 4. Mode of fracture. Split fracture **(a)**, Comminuted fracture **(b)**.

statistically significant differences in fracture resistance between the following group pairs: BIOfactor MTA (4 mm plug) and BIOfactor MTA (full obturation), Biodentine (4 mm plug) and Biodentine (full obturation), Biodentine (4 mm plug) and BIOfactor MTA (4 mm plug), and Biodentine (full obturation) and BIOfactor MTA (full obturation) ($p>0.05$).

Modes of fracture

Two modes of fracture of the roots were recorded: the split vertical fracture mode and comminuted fracture mode (Fig. 4) (13). The most common fracture mode was the split vertical fracture in buccolingual direction in all the groups. The percentages of each mode of fracture are presented in Table 3. The results showed that there is no significant difference between groups based on mode of fracture ($p>0.05$).

Discussion

There are two main approaches for the treatment of open-apex teeth: regenerative endodontic procedure and apexification. Regenerative endodontic treatment is a biological approach that aims to promote continued root development by increasing root length and dentinal wall thickness. This method targets the regeneration of the pulp–dentin complex and represents an important alternative, especially in young patients, due to its potential to preserve tooth vitality (14). In contrast, apexification is a technique designed to create a hard tissue barrier at the root apex of immature teeth and to achieve apical sealing by filling the root canal with biocompatible materials. Apexification has been successfully used in clinical practice for many years, with high reported success rates. However, although apexification is considered a reliable treatment method, immature teeth are prone to fracture due to their thin dentinal walls. The fracture resistance of immature teeth decreases because of weakened root canal dentin, which increases the risk of root fracture. Therefore, selecting an appropriate treatment method for immature teeth is of great importance to reinforce fragile root dentin and improve the prognosis of the tooth (15-17).

Table 3. Mode of fracture for all groups

	Negative Control Group (n:7)	Positive Control Group (n:7)	BIOfactor MTA (4 mm plug) (n:15)	BIOfactor MTA (Full obturation) (n:15)	Biodentine (4 mm plug) (n:15)	Biodentine (Full obturation) (n:15)
Split vertical fracture	71.4% (n:5)	57.1% (n:4)	66.7% (n:10)	80% (n:12)	73.3% (n:11)	86.7% (n:13)
Comminuted fracture	28.6% (n:2)	42.9% (n:3)	33.3% (n:5)	20% (n:3)	26.7% (n:4)	13.3% (n:2)
Fisher- Exact Test			2.209			
p			0.895			

n: Number of samples, $p<0.05$.

In this study, we preferred apexification over regenerative endodontic treatment. The reason for this choice is that our study aimed not to ensure the biological continuation of root development, but rather to compare the effects of different calcium silicate-based materials (Biodentine and BIOfactor MTA) used in apexification treatment on the fracture resistance of immature teeth.

Endodontically treated teeth are considered to be in the high-risk group in terms of root fracture (18,19). It is known that trauma most frequently occurs in maxillary incisors, and these teeth are commonly preferred in clinical studies involving immature teeth (1). In fracture resistance tests of endodontically treated teeth, the type of tooth selected and the direction of the applied force are factors that directly affect the results (20). In central teeth (particularly maxillary central incisors), the natural direction of traumatic forces is typically oblique to the long axis of the root from the labial surface, which is why fractures usually occur in an oblique pattern (21). In the present study, a vertical load was applied to evaluate the fracture resistance of immature teeth. Mandibular premolars were preferred because their anatomical characteristics make them more suitable for this type of loading.

In an in vitro fracture resistance test, the material in which the teeth are embedded should aim to simulate bone by absorbing masticatory forces. Therefore, in this fracture resistance study, we aimed to simulate both bone and periodontal ligament structures before loading the teeth. Periodontal ligament simulation helps prevent stress concentration in a specific area and distributes the stress caused by loading across the entire root surface. Bone and periodontal ligament simulation were performed using acrylic blocks and silicone impression material, respectively (22).

According to the findings of this study, only the negative control group demonstrated a statistically significant difference compared to the other groups, exhibiting the highest fracture resistance ($p<0.05$). Among all experimental groups, the positive control group showed the lowest fracture resistance. Additionally, this study revealed that there was no statistically significant difference in fracture resistance between the groups in which a 4 mm apical plug and full canal obturation were performed using BIOfactor MTA and Biodentine ($p>0.05$). These findings are supportive of our study's hypothesis.

In the present study, the negative control group exhibited a statistically significantly higher fracture resistance compared to all other groups, which represents a clinically important finding. This result highlights the critical role of preserving structural tooth integrity and clearly demonstrates the weakening effects of access cavity preparation, canal instrumentation, and obturation procedures on root dentin. In contrast, the positive control group showed the lowest fracture resistance, which may be explained by the lack of structural support to the dentinal walls as a result of access cavity preparation and canal enlargement without subsequent canal obturation, leading to stress concentration directly on the weakened root dentin. On the other hand, although not statistically significant, the numerically higher fracture resistance observed in the Biodentine groups compared to the BIOfactor MTA groups may be attributed to the smaller particle size of Biodentine, which allows better penetration into dentinal tubules, formation of tag-like structures that enhance micromechanical bonding, and an elastic modulus closer to that of natural dentin (18). Considering that immature teeth are inherently more susceptible to fracture due to their thin dentinal walls, these findings underscore the clinical importance of preserving as much sound tooth structure as possible and adopting minimally invasive treatment approaches to improve prognosis.

According to our results, although there was no statistically significant difference in fracture resistance between the BIOfactor MTA and Biodentine groups and the positive control group, both materials demonstrated higher fracture resistance. Bortoluzzi et al. (17) reported that the fracture resistance of teeth with MTA apical plugs was four times higher compared to roots left unfilled, which is consistent with our study's findings. It has been hypothesized that full obturation of the root canal may lead to increased volumetric expansion of the material and apply pressure on the dentinal walls, potentially reducing fracture resistance. However, no such adverse effect was observed in this study. Similarly, Cicek et al. (4) also reported that despite the expansion property of calcium silicate-based materials, they interact biocompatibly with dentin and do not negatively affect fracture resistance. Therefore, both BIOfactor MTA and Biodentine can be safely used in immature teeth for 4 mm plug placement and full obturation in terms of fracture resistance.

In this study, the fracture resistance of the BIOfactor MTA and Biodentine groups was found to be significantly lower compared to the negative control group. This result may be attributed to the calcium ion release from MTA over time or the neutralization of the acidic nature of dentin by the high alkalinity of MTA during its setting, which can lead to the dissolution of biological matrix components in mineralized dentin and denaturation of the dentin's protein structure (23). Furthermore, previous studies have shown that obturation of root canals with MTA and tricalcium silicate-based materials can reduce fracture resistance due to their lack of elasticity (4,24). One study reported that the use of MTA as a complete filling mate-

rial resulted in a 33% weakening of the tooth structure after five weeks, attributed to protein degradation caused by the material's high alkalinity (25). In another study, intact teeth (negative control group) demonstrated superior fracture resistance after one year compared to teeth completely filled with Biodentine and WMTA (2). Additionally, Topçuoğlu et al. (26) found that simulated immature teeth with apical plugs made of Biodentine had lower fracture resistance compared to intact teeth. The statistically significant higher fracture resistance observed in the negative control group in our study is consistent with and supports the findings of these previous investigations.

In this study, although the Biodentine groups (4 mm plug and full obturation) exhibited higher fracture resistance compared to the BIOfactor MTA groups (4 mm plug and full obturation), this difference was not found to be statistically significant. Similarly, another study reported that the Biodentine group (38.29 MPa) demonstrated higher fracture resistance than the MTA Angelus group (36.72 MPa); however, this difference was not statistically significant (2). Biodentine has been shown to form tag-like connections within the dentinal tubules due to its small particle size, thereby enhancing adhesion. (27). This mechanism may help explain the relatively higher fracture resistance observed in the teeth treated with Biodentine compared to those treated with BIOfactor MTA in this study.

The findings of this study are consistent with previous research that has recommended Biodentine as a preferred material for apical plug applications (25,28). However, a comprehensive literature review revealed no fracture resistance studies evaluating the use of BIOfactor MTA as an apical plug material. Based on the results of this study, we can conclude that BIOfactor MTA demonstrated fracture resistance comparable to that of Biodentine and may be considered a viable alternative calcium-silicate-based material for apexification treatment in immature teeth.

In this study, the most frequently observed fracture type was the split vertical fracture in the buccolingual direction. This finding is consistent with the results of a previously conducted fracture resistance study (13). The predominance of split vertical fractures can be explained by the fact that the applied load during the testing was transmitted parallel to the long axis of the tooth, leading to stress accumulation along the root. Since such fractures usually follow the long axis of the root, the possibility of repair or restoration is quite low, and the prognosis of the tooth is generally poor. In most cases, these types of fractures require extraction of the tooth (1).

Although the findings of the present study provide valuable insights, several limitations should be acknowledged. First, the study was conducted under in vitro conditions; therefore, intraoral factors such as dynamic masticatory forces, temperature fluctuations, moisture balance, and biological influences could not be fully replicated. This limits the direct extrapolation of the results to clinical practice. Second, the study evaluated short-term fracture resistance and did not provide information on long-term biomechanical durability or material–dentin interactions. In particular, potential material degradation and structural changes in dentin over time were not assessed. In addition, vertical loading was applied during fracture resistance testing. However, under clinical conditions, traumatic forces usually act in an oblique direction rather than parallel to the long axis of the tooth. Therefore, the use of vertical loading may not fully represent the direction of traumatic forces encountered clinically and should be considered another limitation of the present study. In addition, the unequal distribution of sample sizes between the control and experimental groups represents a methodological limitation of the study. Although this sample distribution is consistent with experimental designs commonly used in similar in vitro fracture resistance studies reported in the literature (4), the smaller number of specimens in the control groups may have led to reduced statistical power, particularly in these groups. Therefore, future studies are recommended to plan more balanced group sizes to improve statistical power and strengthen group comparisons.

Conclusion

The findings of this study revealed that BIOfactor MTA demonstrated a similar fracture resistance to that of Biodentine. This suggests that BIOfactor MTA may be considered a viable alternative calcium-silicate–based material for apexification procedures. However, long-term in vivo and clinical studies are required to confirm its long-term performance and durability in the oral environment.

Moreover, the absence of a significant difference between the 4 mm plug and full obturation techniques provides clinicians with flexibility in clinical decision-making. Both approaches appear to offer comparable outcomes in terms of fracture resistance, allowing clinicians to select the most appropriate technique based on the specific clinical situation.

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ORIGINAL ARTICLE

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Performances of ChatGPT-4, DeepSeek R1, and Google Gemini in Responding to Periapical Surgery-Related Questions: A Comparative Study

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Purpose: The popularity of artificial intelligence-based chatbots in healthcare is increasing rapidly. In dentistry, they are used for various purposes, including patient education, diagnosis, and treatment planning. This study aimed to evaluate the accuracy and quality of three different AI chatbots, including ChatGPT-4, DeepSeek R1, and Gemini, in answering frequently asked patient questions.

Methods: 25 questions, which were frequently asked by patients in the subject of periapical surgery, were posed to ChatGPT-4, DeepSeek R1, and Gemini. Two independent raters recorded and assessed the recorded responses using a 5-point Likert scale. Also, the quality of the answers was scored using the EQIP scale. ANOVA and Kruskal-Wallis tests were used for the variables. The Spearman correlation test was used to determine the correlation between Likert and EQIP scores.

Results: Geminis' Likert score was significantly lower than ChatGPT-4 and DeepSeek R1 ($p<0.001$). There was no significant difference between ChatGPT-4 and DeepSeek R1 ($p=0.48$). The difference between quality scores was not statistically significant. EQIP and Likert scores within groups showed poor correlation.

Conclusion: Artificial intelligence-based large language models can provide reliable information to patients about periapical surgery. However, there are differences in accuracy and quality between different platforms.

Keywords: Artificial intelligence; dentistry; large language models; oral surgery.

Introduction

Oral surgical procedures increase the stress levels of some patients and cause anxiety. Therefore, patients need to obtain information about the treatment before undergoing these procedures (1). Nowadays, accessing information over the internet has become easier with the aid of artificial intelligence (AI) and large language models (LLMs), which can simplify complex expressions using a few medical terms. Therefore, the reliability and accuracy of the information obtained become more important daily (2).

As AI LLMs have become increasingly popular, they have begun to be used extensively by people in healthcare mat-

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ters and have opened new ways of informing patients. However, several limitations related to using LLMs in healthcare raise concerns about reliability, such as contradictions, inaccuracies, and hallucinations (3). Hallucinations can be defined as instances where an AI-LLM generates text that is contextually or factually incorrect, misleading, or unrelated to the input provided (4). It is a factor that reduces the reliability of the information obtained from LLM platforms.

Apical periodontitis, also known as chronic inflammatory disease of periapical tissues, has a high prevalence of 39% in root canal-treated teeth (5). Although this condition can be treated with endodontic retreatment, periapical surgery has emerged as the preferred treatment approach when performing a specific risk-benefit analysis (6). Periapical surgery is an oral surgical procedure used to treat teeth with persistent periapical pathologies that have not responded to appropriate endodontic treatment or retreatment (7). As an alternative to extraction, this procedure is commonly performed worldwide (8). Technological advancements in endodontics and oral surgery positively impact the accuracy and success rate of the procedure, making it a more reliable option daily (9). In recent years, several studies have reported success rates of up to 90% in periapical surgery (10,11). However, Del Fabbro et al. (12) reported no clear evidence of the superiority of either a nonsurgical or a surgical approach. Therefore, establishing a reliable decision-making mechanism between surgical and nonsurgical approaches is difficult. Additionally, the presence of surgical morbidity complication risks leads patients to perform more research on the choice of surgical treatment. However, no comparative study has been conducted with ChatGPT, DeepSeek, and Gemini in oral surgery or dentistry.

This study aimed to compare the accuracy and quality of answers given by three popular LLMs -Chat GPT, DeepSeek R1, and Gemini- to patient questions about periapical surgery. The null hypothesis of this study was that there would be no difference in the accuracy and quality of responses among ChatGPT-4, DeepSeek R1, and Gemini when answering patient questions related to periapical surgery.

Materials and Methods

Since the LLMs used in this study are publicly available platforms, the study was exempt from Institutional Ethics Committee approval.

The questions were collected from patients who were scheduled for periapical surgery during routine clinical consultations over a defined period. Repeated or semantically similar questions were grouped, and the 25 most frequently encountered questions were selected by consensus of the authors. These questions were then posed to the LLM platforms ChatGPT-4, DeepSeek R1, and Gemini. A new chat window was opened for each question to minimise interaction between the answers on each platform, and the answers were recorded. The exact standardized question text was used for all three LLMs. All questions were submitted in Turkish, reflecting the native language of the patient population. Queries were entered once for each model on the same day and within the same time frame to minimize temporal variability. Response consistency over repeated time points was not evaluated. An experienced oral and maxillofacial surgeon and endodontist assessed the answers via a 5-point Likert scale (Table 1) with the following grades: “Completely incorrect” (0 points), “generally incorrect” (5 points), “overall acceptable” (10 points), “correct” (15 points), and “entirely correct” (20 points). The evaluations were conducted based on current scientific literature and established clinical guidelines related to periapical surgery. Accuracy was determined by comparing the LLM-generated responses with contemporary evidence-based knowledge and standard clinical practice.

Content quality was additionally assessed using a modified version of the Ensuring Quality Information for Patients (EQIP) tool. Although the original EQIP instrument consists of 36 items, a 28-item version was used in the present study, consistent with previously published methodology. The selected items evaluated both content-related aspects (items 1–18), including accuracy, completeness, and balance of information, and structural aspects (items 19–28), such as clarity, organization, and readability. Each EQIP item was scored using a binary system (yes/no), with a “not applicable” option when appropriate. The total EQIP score for each response was calculated by summing the number of criteria fulfilled, with higher scores indicating higher information quality (13,14).

Statistical Analysis

The statistical analysis was performed via IBM SPSS Statistics version 26.0. The normality of the data was evaluated via the Shapiro-Wilk test. While the Kruskal-Wallis test was

Table 1. 5-Point Likert scale

Level	Description	Point
1	Completely incorrect	0 points
2	Generally incorrect	5 points
3	Overall acceptable	10 points
4	Correct	15 points
5	Entirely correct	20 points

Table 2. Likert and EQIP scores of each questions that answered by chatbots

No	Questions	ChatGPT-4		DeepSeek R1		Gemini	
		Likert Score	EQIP Score	Likert Score	EQIP Score	Likert Score	EQIP Score
1	What is periapical surgery?	15	13	15	20	7.5	19
2	On which teeth can periapical surgery be performed?	12.5	10	17.5	11	15	19
3	What are the complications of periapical surgery?	17.5	16	15	10	12.5	17
4	What are my alternative treatment options if I don't want to have periapical surgery?	15	17	15	18	10	11
5	Who can perform periapical surgery?	12.5	12	20	10	12.5	12
6	Will I feel pain during the periapical surgery procedure?	15	14	15	16	12.5	15
7	How long does an periapical surgery procedure take on average?	12.5	8	17.5	10	17.5	14
8	Will there be swelling on my face after the periapical surgery?	17.5	17	15	13	12.5	17
9	Can periapical surgery be performed without root canal treatment?	5	14	5	9	7.5	13
10	What should I pay attention to after periapical surgery?	17.5	15	15	16	12.5	19
11	What will happen if the periapical surgery procedure fails?	12.5	11	15	15	7.5	16
12	Will the filling material placed on the cut root tip dissolve over time after periapical surgery?	12.5	12	17.5	9	10	8
13	Will the lifespan of the tooth be shortened after periapical surgery due to root shortening?	17.5	13	17.5	18	10	14
14	Will there be any looseness in my teeth after periapical surgery?	20	10	17.5	20	17.5	17
15	Is there a possibility of having periapical surgery under general anesthesia?	12.5	9	15	11	10	11
16	Will I need to take medication after the periapical surgery operation?	17.5	12	20	18	7.5	7
17	Will I be able to eat after periapical surgery?	12.5	13	12.5	14	15	11
18	How much will I have to pay for the periapical surgery procedure?	5	12	2.5	12	12.5	10
19	Will I experience any negative consequences if I don't have this procedure?	12.5	18	17.5	19	10	15
20	If I experience the same complaints in the tooth I had periapical surgery before will the procedure be repeated?	12.5	17	17.5	14	12.5	12
21	Can an implant be placed if this tooth is extracted in the future?	15	15	15	11	17.5	11
22	What is the success rate of periapical surgery?	17.5	14	17.5	15	12.5	10
23	How long after root canal treatment can periapical surgery be performed?	15	9	15	17	5	8
24	Can periapical surgery be performed at any age?	15	14	17.5	14	5	10
25	Does having a chronic illness prevent me from having periapical surgery?	12.5	14	15	13	7.5	12

used for the statistical analysis of non-normally distributed data, ANOVA was used for normally distributed data. The Spearman correlation test was used to assess the correlation between the Likert scale and EQIP scores within each group. Inter-rater reliability between the two evaluators was assessed using the intraclass correlation coefficient (ICC) based on a two-way mixed-effects model with absolute agreement.

Results

All questions and the scores of each question are provided in Table 2. Also, EQIP criteria and response rates are presented in Table 3.

The mean Likert scores for 25 responses from the ChatGPT-4, DeepSeek R1, and Gemini platforms were 14±0.7, 15.3±0.78, and 11.2±0.72, respectively. There was no significant difference between ChatGPT and DeepSeek's Likert scores. However, Gemini had significantly lower scores than the other groups ($p<0.001$) (Fig. 1). The mean quality scores for each platform were 13.16±2.71, 14.12±3.50, and 13.12±3.57, with no significant difference ($p=0.48$). Likert and EQIP scores are presented in Table 4. The correlations between the accuracy and quality scores of each LLM were evaluated via the Spearman test. However, the accuracy and quality scores were weakly correlated in all LLMs (ChatGPT, $r=0.208$, $p=0.318$; – DeepSeek, $r=0.126$, $p=0.59$; – Gemini, $r=0.301$, $p=0.144$). Table 5 presents the correlation coefficients between Likert and EQIP scores within each group.

Inter-rater reliability was assessed using the intraclass correlation coefficient (ICC) based on a two-way mixed-effects model with absolute agreement. The single-measure ICC was 0.404 (95% CI: 0.191–0.579, $p<0.001$). Given this level of reliability, all subsequent analyses were conducted using the average of the two raters' measurements. Accordingly, the average-measure ICC was 0.575 (95% CI: 0.321–0.733, $p<0.001$), indicating moderate inter-rater reliability.

Discussion

The research evaluated the accuracy of three popular large language models, ChatGPT-4, DeepSeek R1, and Gemini, in responding to common patient inquiries about periapical surgery. The results indicated ChatGPT-4 and DeepSeek R1 achieved better accuracy results than Gemini, but the three models delivered similar overall quality performance. The researchers rejected the null hypothesis regarding accuracy measurements but failed to reject the null hypothesis for quality results.

Artificial intelligence has undoubtedly been at the forefront of technological advancements worldwide in recent years, and its influence has been increasingly extending into healthcare and clinical practice. Tools based on artificial intelligence are having an increasing impact on all areas of life, not just industry and science (15). In addition to searching engines on the internet, people are trying to access information on any subject they are curious about by using artificial intelligence chat platforms. The healthcare sector is also affected by this change. Increasingly, patients are seeking information about diagnosis and treatment procedures involving artificial intelligence language models before or after consulting a healthcare professional (16). While this situation eases the burden on healthcare providers to educate patients, it also raises concerns about the accuracy and validity of the information received (17).

In the literature, numerous studies have evaluated ChatGPT's reliability, validity, and accuracy in different dentistry fields. A study evaluated the quality of patient information and educational content generated by ChatGPT regarding oral and maxillofacial surgery. It reported that the usability of patient information was superior to that of educational information generated by ChatGPT (18). Another study evaluating the quality of dental information on preventive dentistry, oral surgery, and oral cancer obtained from ChatGPT found that information on preventive dentistry had higher scores. It was reported that some limitations may be encountered in areas requiring nuanced expertise, such as oral surgery (19). Our study considered periapical surgery, a specialised operation within the scope of oral surgery, and ChatGPT, which was compared with relatively new language models. Examples of studies conducted with similar approaches using ChatGPT in different specialities of dentistry can be increased. Many of these studies have reported that ChatGPT provides reliable and high-quality patient information; however, this does not mean that all the information is safe (20-23).

The assessment of AI-based patient information tools needs to evaluate both their accuracy and performance quality. However, the three platforms demonstrate poor connections between Likert and EQIP scores, indicating that these domains do not improve simultaneously. The criteria for high-quality educational material require more than factual accuracy, because an answer that contains correct information may still fail to meet standards for completeness, structure, patient-centeredness, and clarity. The current LLMs exhibit a functional limitation because they produce accurate medical information, but they cannot create comprehensive explanations that patients can understand. The ability of an AI chatbot to provide accurate information does not guarantee its effectiveness for patient education, as patients who require periapical surgery

Table 3. EQIP criteria and response rates

		ChatGPT-4			DeepSeek R1			Gemini		
		Yes	No	N/A	Yes	No	N/A	Yes	No	N/A
Item 1	Initial definition of which subjects will be covered	15 (60%)	10 (40%)	0 (0%)	23 (92%)	2 (8%)	0 (0%)	18 (72%)	7 (28%)	0 (0%)
Item 2	Coverage of the previously defined subjects (NA if the answer is "no" for item 1)	14 (56%)	1 (4%)	10 (40%)	22 (88%)	1 (4%)	2 (8%)	17 (68%)	1 (4%)	7 (28%)
Item 3	Description of the medical problem/ treatment/procedure	10 (40%)	15 (60%)	0 (0%)	8 (32%)	17 (68%)	0 (0%)	12 (48%)	13 (52%)	0 (0%)
Item 4	Definition of the purpose of the interventions	6 (24%)	19 (76%)	0 (0%)	6 (24%)	19 (76%)	0 (0%)	9 (36%)	16 (64%)	0 (0%)
Item 5	Description of treatment alternatives (conservative management)	7 (28%)	17 (68%)	1 (4%)	9 (36%)	16 (64%)	0 (0%)	4 (16%)	21 (84%)	0 (0%)
Item 6	Description of the sequence of the interventions and surgical procedure	2 (8%)	23 (92%)	0 (0%)	3 (12%)	22 (88%)	0 (0%)	3 (12%)	22 (88%)	0 (0%)
Item 7	Description of the qualitative benefits for the patient	7 (28%)	18 (72%)	0 (0%)	8 (32%)	17 (68%)	0 (0%)	5 (20%)	20 (80%)	0 (0%)
Item 8	Description of the quantitative benefits to the patient	1 (4%)	24 (96%)	0 (0%)	5 (20%)	20 (80%)	0 (0%)	4 (16%)	21 (84%)	0 (0%)
Item 9	Description of the qualitative risks and complications	13 (52%)	11 (44%)	1 (4%)	13 (52%)	12 (48%)	0 (0%)	10 (40%)	15 (60%)	0 (0%)
Item 10	Description of the quantitative risks and complications	9 (36%)	15 (60%)	1 (4%)	13 (52%)	12 (48%)	0 (0%)	8 (32%)	17 (68%)	0 (0%)
Item 11	Addressing quality-of-life-issues	7 (28%)	16 (64%)	2 (8%)	11 (44%)	14 (56%)	0 (0%)	10 (40%)	15 (60%)	0 (0%)
Item 12	Description of how complications are handled	1 (4%)	24 (96%)	0 (0%)	6 (24%)	19 (76%)	0 (0%)	3 (12%)	22 (88%)	0 (0%)
Item 13	Description of the precautions that the patient may take	5 (20%)	19 (76%)	1 (4%)	7 (28%)	18 (72%)	0 (0%)	7 (28%)	18 (72%)	0 (0%)
Item 14	Mention of alert signs that the patient may detect	8 (32%)	17 (68%)	0 (0%)	10 (40%)	15 (60%)	0 (0%)	7 (28%)	18 (72%)	0 (0%)
Item 15	Addressing medical intervention costs and insurance issues	1 (4%)	24 (96%)	0 (0%)	2 (8%)	23 (92%)	0 (0%)	2 (8%)	23 (92%)	0 (0%)
Item 16	Specific contact details for hospital services (NA if not hospitals)	1 (4%)	24 (96%)	0 (0%)	1 (4%)	24 (96%)	0 (0%)	0 (0%)	25 (100%)	0 (0%)
Item 17	Specific details of other sources of reliable information/support	7 (28%)	18 (72%)	0 (0%)	0 (0%)	25 (100%)	0 (0%)	3 (12%)	22 (88%)	0 (0%)
Item 18	Coverage of all relevant issues for the topic (summary item) for all content criteria))	21 (84%)	3 (12%)	1 (4%)	23 (92%)	2 (8%)	0 (0%)	17 (68%)	8 (32%)	0 (0%)
Item 19	Use of everyday language and explanation of complex words or jargon	25 (100%)	0 (0%)	0 (0%)	25 (100%)	0 (0%)	0 (0%)	25 (100%)	0 (0%)	0 (0%)
Item 20	Use of generic names for all medications or products (NA if no medications described)	2 (8%)	7 (28%)	16 (64%)	2 (8%)	7 (28%)	16 (64%)	0 (0%)	9 (36%)	16 (64%)
Item 21	Use of short sentences (<15 words on average)	25 (100%)	0 (0%)	0 (0%)	25 (100%)	0 (0%)	0 (0%)	25 (100%)	0 (0%)	0 (0%)
Item 22	Personal address to the reader	25 (100%)	0 (0%)	0 (0%)	21 (84%)	4 (16%)	0 (0%)	25 (100%)	0 (0%)	0 (0%)
Item 23	Respectful tone	25 (100%)	0 (0%)	0 (0%)	25 (100%)	0 (0%)	0 (0%)	25 (100%)	0 (0%)	0 (0%)
Item 24	Clear information (no ambiguities or contradictions)	25 (100%)	0 (0%)	0 (0%)	18 (72%)	7 (28%)	0 (0%)	21 (84%)	4 (16%)	0 (0%)
Item 25	Balanced information on risks and benefits	17 (68%)	7 (28%)	1 (4%)	17 (68%)	8 (32%)	0 (0%)	18 (72%)	7 (28%)	0 (0%)
Item 26	Presentation of information in a logical order	24 (96%)	1 (4%)	0 (0%)	25 (100%)	0 (0%)	0 (0%)	25 (100%)	0 (0%)	0 (0%)
Item 27	Satisfactory design and layout (excluding figures or graphs; see next item)	25 (100%)	0 (0%)	0 (0%)	25 (100%)	0 (0%)	0 (0%)	25 (100%)	0 (0%)	0 (0%)
Item 28	Clear and relevant figures or graphs (NA if absent)	1 (4%)	2 (8%)	22 (88%)	0 (0%)	0 (0%)	25 (100%)	0 (0%)	0 (0%)	25 (100%)

Table 4. Average Likert and EQIP scores of each AI based LLM

	ChatGPT-4		DeepSeek R1		Gemini		
	Mean±SD	Median (min-max)	Mean±SD	Median (min-max)	Mean±SD	Median (min-max)	p
Likert Scores	14±0.7a	15 (5-20)	15.3±0.78[a]	15 (2.5-20)	11.2±0.72[b]	12.5 (5-17.5)	<0.001*
EQIP Scores	13.16±2.71	13 (8-18)	14.12±3.50	14 (9-20)	13.12±3.57	12 (7-19)	p=0.48**

*Kruskall Wallis-H test with Bonferoni correction. ** One-way ANOVA. †SD: standart deviation. min: Minimum max: Maximum. ‡a-b: No significant difference exists between values sharing the same letter.

Table 5. Correlation between Likert and EQIP scores within groups

	Lickert Scores		EQIP Scores	
	r	p*	r	p*
Chat GPT				
Likert Scores			0.208	0.318
EQIP Scores	0.208	0.318		
DeepSeek				
Likert Scores			0.126	0.549
EQIP Scores	0.126	0.549		
Gemini				
Likert Scores			0.301	0.144
EQIP Scores	0.301	0.144		

*Spearmann correlation test. †r: correlation coefficient.

information often seek detailed, step-by-step guidance with emotional support.

Although the use of ChatGPT still appears to be far ahead, it faces tough competition from artificial intelligence-based chatbots developed by various companies, such as Google's Gemini and DeepSeek R1. In 2023, Google launched its latest multimodal AI tool, Gemini (24). Gemini was rated as the most preferred chatbot in blind evaluations, with high accuracy and reliability rates in understanding and processing complex tasks (25). Strzalkowski et al. (26) compared the accuracy and readability of ChatGPT and Gemini in answering questions about retinal detachment. Their study categorised the questions into three difficulty levels. ChatGPTs' and Geminis' scores were not significantly different at the first and second levels, but GPTs were superior to Gemini at the third difficulty level. In another study, 64 questions about orthognathic surgery were posed to Chat GPT-3.5, 4, and Gemini. ChatGPT-4 and Gemini demonstrated the highest accuracy in answering closed-ended questions (27). Taymour et al. (28) also reported in a study on the topic of prosthodontics that Google Gemini made a difference by providing answers consistent with expert consultations, compared to ChatGPT-3.5 and 4 (28). However, in our study, Gemini exhibited significantly lower accuracy scores than Chat GPT-4 and DeepSeek R1, demonstrating similar quality scores. These results are consistent with other studies in the literature (29,30). Several factors may account for Gemini's comparatively lower accuracy scores in the present study. The training methods used for model development, along with the level of domain-specific model adjustment, influence the performance of models when working with dental content related to periapical surgery. The system Gemini shows excellent results in general and multimodal tasks, according to research studies (24,25). However, it generates answers based on general medical information rather than dental procedure knowledge. Additionally, all questions were submitted in Turkish, and variations in multilingual training data across models may differentially affect response precision (26,30). The way Gemini chooses to explain things results in answers that receive decent quality marks but lack sufficient detailed information, thereby lowering the accuracy ratings.

Since January 2025, DeepSeek's DeepThink (R1) has introduced new momentum to the application of generative artificial intelligence in healthcare, thanks to its continuous learning capabilities, offline deployment options, and collaborative potential (31). Additionally, DeepSeek reduced the financial costs with its open-source advanced LLM (32). Despite the potential promise of DeepSeek's DeepThink (R1), real-world data evaluating its performance in healthcare are still lacking, especially empirical metrics comparing its effectiveness, accuracy, and reliability to those of proprietary models, such as ChatGPT and Gemini (31). The study by Marcaccini et al. (33), comparing ChatGPT -4, DeepSeek V3, and Gemini, is similar to our study in terms of the tools used (33). They found that ChatGPT-4o demonstrated the highest accuracy in hand fractures. However, this is the first study to compare ChatGPT, DeepSeek, and Gemini in the field of dentistry.

One of the most obvious limitations of this study is the lack of standardisation in preparing the questions, which were based only on the authors' experience. This may limit the external validity of the results, as the questions may not comprehensively reflect the information needs of patients from different populations or healthcare systems.

Another limitation is the small number of raters. Although inter-rater reliability was assessed, a limited number of evaluators may reduce statistical power and influence the stability of the scoring outcomes. Periapical surgery is a specialty of general dentistry, periodontology, oral and maxillofacial surgery, and endodontics. Therefore, the absence of reviewers from all related specialties may have influenced the interpretation of specific clinically nuanced responses. Finally, the number of AI-based LLMs included in the evaluation could have increased to compare the performance of more chatbots. This limits the scope of the conclusions to the evaluated platforms and restricts broader generalization to other available or emerging LLMs.

The research findings show that AI-generated responses function as educational materials that healthcare providers can distribute to patients for learning periapical surgery techniques. The accuracy of chatbots does not guarantee that they will deliver information that meets patient needs for complete understanding and decision-making capability. The tools enhance communication efficiency, but they should function as additional resources that do not replace the professional clinical decisions made by doctors.

Conclusion

Artificial intelligence technology enables large language models to assist patients seeking information about periapical surgery through their information retrieval system. DeepSeek R1 achieved results that matched those of ChatGPT-4 in terms of accuracy, while obtaining quality scores that matched both platforms. However, the chatbots showed different levels of performance. The research results demonstrate that AI-generated content should work in conjunction with expert clinical advice, rather than replacing it. Future studies, including a broader range of LLMs, more diverse clinical scenarios, and larger reviewer groups, will help clarify the extent to which such tools can be integrated safely and effectively into patient education.

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ORIGINAL ARTICLE

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Preparing the S-Shape Canal: Does Coronal Enlargement Prevent Transportation?

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Purpose: This study evaluated the effects of coronal enlargement files with different tapers, apical diameters, and heat treatments on canal transportation in standardized S-shaped simulated canals.

Methods: Sixty resin blocks with a 50° double curvature were assigned to four groups (n=15): UniGold Sx, UniBlue Sx, N1, and Control. All canals were prepared to size 25/.04 using the K7 system. Pre- and post-instrumentation images were superimposed in Fiji, and transportation was measured at five levels. ANOVA and Bonferroni tests were used (α=0.05).

Results: No significant differences were observed at the apical constriction. At 2 mm, coronal enlargement groups showed transportation opposite the furcation, whereas the control group showed transportation toward it ($p<0.05$). At 5 and 8 mm, the N1 group exhibited the least transportation ($p<0.05$). UniGold Sx showed the highest transportation at 11 mm ($p<0.05$).

Conclusion: Minimally invasive, flexible files reduced transportation in critical areas, while all forms of coronal preparation improved apical shaping safety.

Keywords: Canal transportation; coronal enlargement; root canal preparation; S-shaped canal.

Introduction

The use of NiTi files in root canal treatment with inappropriate sizes or incorrect techniques can lead to procedural errors, such as transportation, ledge formation, or zip, especially in curved root canals (1,2). These errors increase the risk of perforation, especially on thin dentin walls (3). Irregular canal anatomy resulting from procedural errors complicates not only chemomechanical preparation but also the hermetic sealing (2).

Considering the variations in root canal anatomy, S-curvature canals are one of the most challenging morphologies in endodontic treatments. In these types of root canals, the stress accumulated on the endodontic files may increase the risk of instrument fracture. Metallurgical and thermomechanical processing enhance the flexibility of NiTi rotary instruments, thereby increasing their resistance to torsional and flexural forces (4,5). While increasing the diameter and taper of root canal files reduces their ability to follow the root canal curvature, heat processing applied to the NiTi aims to compensate for this drawback and enhance their flexibility. There is no universal "ideal system" among the systems currently available on the market. Thus, the use of mixed file systems that combine the advantages of various designs is intended to minimize canal

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transportation while supporting effective chemomechanical disinfection. This approach can reduce the frequency of procedural errors by combining the benefits of different file systems (6).

Produced as a counterpart to the TruNatomy system, the RS Narrow system is manufactured from 0.8 mm NiTi wire that has undergone special heat treatment, exhibiting superelastic properties and a reduced shape memory effect. The N1 Opener used for coronal enlargement has a triangular cross-section, an ISO 20 apical diameter, and a 0.08 taper; its active part is 7 mm. This design is suitable for minimally invasive approaches (7). UniGold and UniBlue Systems are produced as counterparts to Protaper Universal (PTU) and share similar properties with PTU. Both systems are manufactured from heat-treated NiTi alloy. The UniGold system has an Af temperature of 22 °C. Therefore, it remains completely in an austenitic phase under clinical conditions. This provides the endodontic files with high elasticity, shape memory, and maximum cutting efficiency (8,9). For the UniBlue system, the Af temperature is close to body temperature. Although this system adapts better to the canal morphology due to high flexibility, cutting efficiency is lower due to the softer structure. It can be preferred in curved and narrow canals to reduce the risk of procedural errors (10).

Coronal enlargement facilitates both mechanical shaping and apical access of irrigation solutions by allowing the files to move freely in the root canal. As chemomechanical disinfection becomes more effective, iatrogenic errors that may occur in the apical region decrease (11,12). Although coronal enlargement files with high taper facilitate apical access, they may cause excessive dentin loss in the servical area, reducing the fracture resistance of the tooth (13). Conversely, low-taper coronal enlargement files preserve dentin better but may hinder apical access, increasing the risk of errors such as transportation or ledge formation. Therefore, the taper, apical diameter, and heat treatment of the file system play an essential role in long-term tooth preservation.

This study aimed to evaluate the effects of coronal enlargement files differing in terms of taper, apical diameter, and heat processing on root canal transportation in teeth with S-shaped curvature. The null hypothesis (H0) of the study is that different coronal enlargement files will show similar results in terms of root canal transportation and apical transportation.

Materials and Methods

The sample size of the study was calculated based on the reference study, assuming a statistical power of 90% and a large effect size, resulting in 20 samples per group (14). A total of sixty simulated S-shaped resin canal blocks were manufactured specifically for this study. Each block contained a standardized canal with an apical diameter of 0.15 mm, 2% taper, and a total length of 18 mm. The first 5 mm of the block is designed to mimic the access cavity. The remaining 13mm of the block is designed to create an S-shaped canal configuration (15). Both the coronal

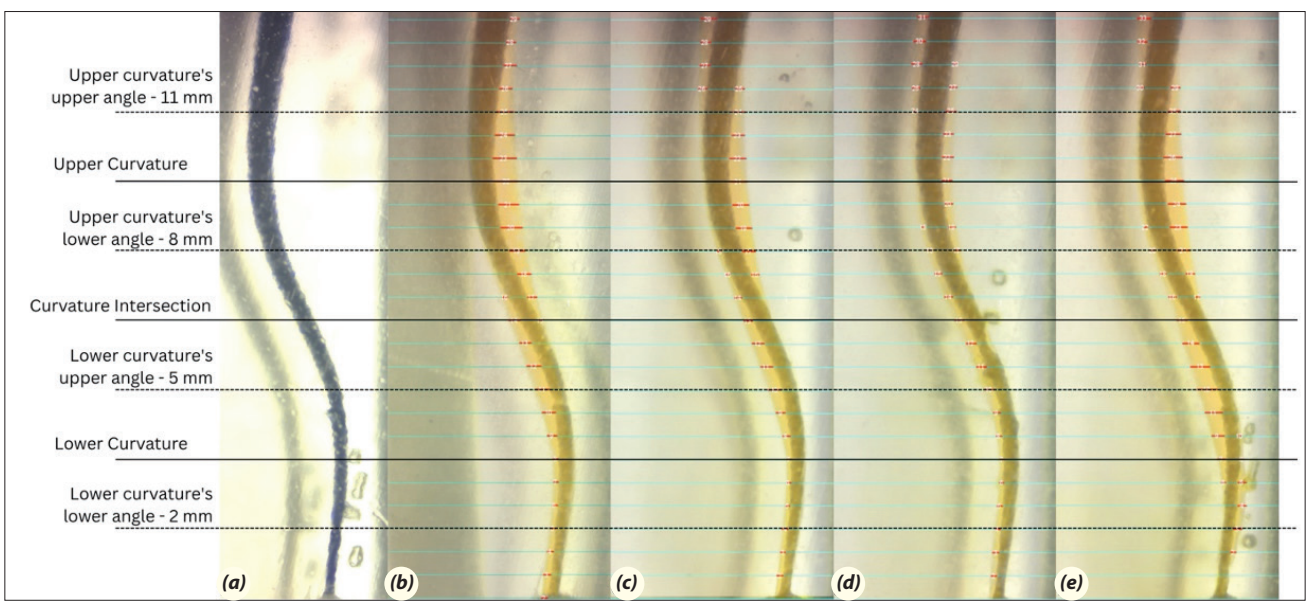

Fig. 1. Pre-instrumentation (a) and post-instrumentation (b-e) images of the standardized S-shaped simulated root canal blocks.
B: UniGold Sx; C: UniBlue Sx; D: N1; E: Control.

curvature and the apical curvature were designed to have an angle of 50° with a radius of 6 mm. These values were selected to simulate an anatomically challenging natural S-shaped root canal morphology with two curves (Fig. 1A). Canal patency was confirmed using a size 15 stainless steel K-file (Dentsply Maillefer, Ballaigues, Switzerland).

All resin blocks were stabilized in a custom-made holder to ensure a fixed position, thereby maximizing standardization and minimizing operator-induced variability. Before instrumentation, all simulated canals were stained with methylene blue dye to enhance visibility of the canal outline. Each specimen was numbered, and baseline stereomicroscope images (Zeiss Stemi 2000-C; Zeiss, Germany) were obtained at 10x magnification and recorded for subsequent comparison (Y.K.).

The entire procedure was performed under an operating microscope at ×10 magnification (OPMI Pico, Zeiss, Germany). Canal patency was confirmed with a size 15 stainless steel K-file (Dentsply Maillefer, Ballaigues, Switzerland) using gentle in-and-out pecking motions. All preparations were performed by a single experienced operator (G.E.K) to eliminate inter-operator variability. One rotary file was used for every three resin blocks. Instrumentation was performed using a torque-controlled motor (Woodpecker AI Endomotor, Guilin Woodpecker Medical Instrument Co., Ltd., Guangxi, China) with preset parameters according to the manufacturer's instructions.

The experimental groups were prepared as follows:

• Group UniGold Sx: The coronal portion of the canal was enlarged with UniGold Sx (Scope Endodontic System, Yozgat, Türkiye). Canal preparation was then completed using the K7 system (Scope Endodontic System, Yozgat, Türkiye) with 20/.04 and 25/.04 files to the full working length.

• Group UniBlue Sx: The coronal third was enlarged with UniBlue Sx (Scope Endodontic System, Yozgat, Türkiye). Final shaping was performed using K7 system 20/.04 and 25/.04 files to the working length.

• Group N1: Orifice enlargement was performed using the RS Narrow 1 (Scope Endodontic System, Yozgat, Türkiye). Subsequent shaping was completed using the K7 system with 20/.04 and 25/.04 instruments to the full working length.

• Group Control: No orifice opener was used. After a patency check with a size 15 K-file, instrumentation was performed directly with the K7 system using 20/.04 and 25/.04 files up to the full working length.

In all groups, instrumentation was performed using gentle in-and-out pecking motions with an amplitude of less than 3 mm. Coronal enlargement files were used with a working length of 10 mm. Copious irrigation with 10 mL of distilled water was performed after each file using a 30-gauge side-vented irrigation needle (NaviTip, Ultradent, USA). The final apical preparation size was standardized at 25/.04 in every canal. The canals were dried with paper points (DiaDent, Cheongju, South Korea).

After the instrumentation process, the canals were refilled with red ink to delineate the canal space for photographic analysis. Post-instrumentation images were then captured under identical microscopic conditions (10x magnification) to enable precise comparison with the baseline images (Y.K.). The examiner was blinded to the group allocation; all specimens were evaluated using numerical codes, and decoding was performed only after the completion of the image analysis.

Preoperative and postoperative images were superimposed using Fiji software (Fig. 1), and the transportation of the root canal was measured in millimeters using a 188-pixel/mm scale (14). Twenty-six measurements were made on the images with 0.5 mm intervals from apical to coronal. Canal transportation was evaluated at 2, 5, 8, and 11 mm from the apical foramen, representing the lower curvature's lower and upper, and the upper curvature's lower and upper, respectively (16). Additionally, transportation of apical constriction was evaluated by measuring 0.5 mm from the apical foramen.

The formulation that (a1–a2)–(b1–b2), was used to measure the degree of canal transportation, where: (a1-a2) = the difference between the instrumented canal periphery and the uninstrumented canal periphery in the direction opposite the furcation, (b1-b2) = the difference between the instrumented canal periphery and the uninstrumented canal periphery in the furcation direction (17).

Based on the idea that S-shaped root canal anatomy is most frequent in the upper molar palatal root canals, the inner side of the coronal curvature was referred to as the 'furcation direction' and the outer side as the 'anti-furcation' direction throughout the study. According to the formulations, a "0" result indicates that there is no transport. At the same time, positive values mean that there is canal transportation in the direction opposite to the furcation, and negative values mean that there is canal transportation in the direction of the furcation.

Statistical Analysis of Data

Statistical analyses were performed using GraphPad Prism software (version 10.0, GraphPad Software, San Diego, CA, USA). The Shapiro-Wilk test was used to evaluate the normal distribution of the data, and parametric tests were used. One-way analysis of variance was used to as-

Table 1. Mean ± standard deviation of canal transportation (mm) at each measurement level for all experimental groups. Different superscript letters within the same row indicate statistically significant differences among groups, as determined by post-hoc comparisons (p<0.05). Positive values denote transportation opposite to the furcation direction, and negative values toward the furcation direction.

	UniGold Sx	UniBlue Sx	N1	Control	p Value
11 mm	-0.323±0.055[a]	-0.260±0.065[ab]	-0.227±0.086[b]	-0.186±0.151[b]	0.002
8 mm	-0.289±0.129[a]	-0.243±0.028[a]	-0.113±0.135[b]	-0.241±0.135[a]	0.003
5 mm	0.317±0.085[a]	0.296±0.088[ab]	0.227±0.066[b]	0.355±0.107[a]	0.002
2 mm	0.053±0.092[a]	0.007±0.082[ab]	0.016±0.112a[b]	-0.059±0.141[b]	0.047
Apical Foramen	0.086±0.086	0.029±0.074	0.055± 0.084	0.038±0.104	0.314

sess whether there were any differences between the four groups at 0.5 mm, 2 mm, 5 mm, 8 mm, and 11 mm in transportation. In cases where the tests detected significant differences, post hoc pair-wise comparisons were performed using the Bonferroni test. Statistical significance was set at 5%.

Results

The mean and standard deviation values for transportation at the five different levels for all groups are shown in Table 1. At the 2 mm level, transportation occurred in the opposite direction of furcation in the UniGold Sx, UniBlue Sx and N1 groups. In contrast, in the control group, transportation occurred in the direction of furcation (p=0.047). At 5 and 8 mm levels, canal transportation in the N1 group was significantly lower than in the other groups (p=0.002 , p=0.003), being in the opposite direction to the furcation at the 5 mm level and in the direction of the furcation at the 8 mm level. At the 11 mm level, the UniGold Sx group showed significantly higher canal transportation than the other groups (p=0.002). No difference was observed between the groups in terms of apical foramen transportation (p=0.315).

Upon examination of these results, it was observed that dentin removal occurred on the inner walls of the curvatures in all groups; however, different enlargement files exhibited varying levels of transportation patterns (Fig. 2).

Discussion

Mechanical preparation plays a critical role in the success of root canal treatment. Using appropriate file combinations enhances mechanical shaping while preserving structural integrity, with minimal impact on fracture resistance (18,19). It is important to evaluate the effects of taper, apical diameter and heat processing of root canal files on transportation (14).

The flexibility of NiTi files and their ability to adapt to the canal anatomy contribute to preserving the biomechanical strength of the tooth by minimizing dentin loss (17,20). However, as the file engages in curved canals, it tends to flatten due to the shape memory effect. This effect becomes more pronounced, especially in double-curved S-shaped root canals (6). This may cause asymmetric dentin removal on particular walls of the root canal, leading to canal transportation (1) (Fig. 2).

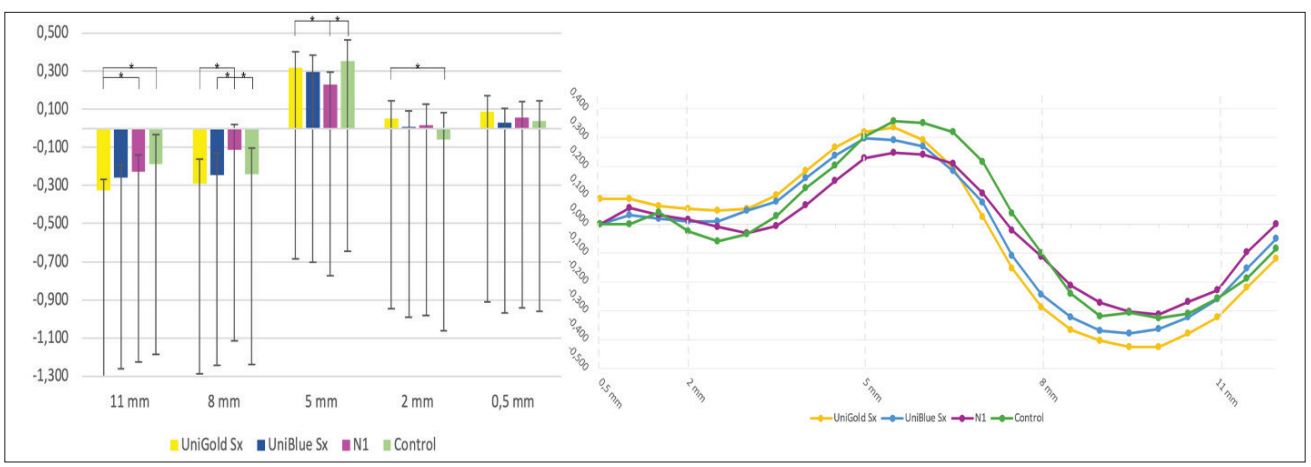

Fig. 2. Graphical representation of canal transportation at predefined measurement levels. The left graph illustrates the mean canal center shift along the canal path for all instrument groups (UniGold Sx, UniBlue Sx, N1, and Control). The right panel shows the magnitude and direction of transportation at each measurement level (11 mm, 8 mm, 5 mm, 2 mm, and apical foramen).

In the present study, 11 mm and 8 mm were defined as the upper and lower angles of the upper curvature, respectively, and dentin removal was observed in the direction of furcation in all groups. The highest transportation value was observed in the UniGold Sx group and the lowest in the N1 group. It is thought that the longer cutting area, higher apical diameter, and taper of the UniGold Sx, along with its more rigid structure, which benefits from its distinctive heat treatment compared to other groups, increase transportation in this group. In the control group, the narrow angle at the cervical region caused the removal of more material from the furcation wall of the curvature. Based on these findings, the use of more minimally invasive coronal preparation files appears advantageous in anatomically vulnerable areas such as the 'danger zone'. Morales et al. (19) reported that preparation using files with a lower taper resulted in less dentin removal from the coronal part of the root canal. In contrast, Alqahtani et al. (3) reported that coronal enlargement did not affect root canal transportation. Although coronal enlargement is the correct approach to reduce canal transportation by eliminating the narrow angulation in the cervical region of the root canal, the taper of the file used in this approach is essential to preserve the original shape of the canal.

5 mm and 3 mm were defined as the upper and lower angles of the lower curvature, respectively. In both regions, it is located apical to the transition zone, which is the point where the two curvatures meet. As the curvature reverses in the transition zone, the high stress on the file increases the memory shape effect, causing the removal of more dentin from the inner wall of the curvature (21,22). In the present study, there was more contact with the inner surface of the lower curvature in all groups; this caused transportation in the opposite direction of the furcation in the experimental groups. At these levels, the highest canal transportation was observed in the control group and in the direction of the furcation. The difference in the direction of transportation between the experimental and control groups was attributed to the reduction of the shape memory effect on the file by coronal enlargement (23,24). Based on these results, performing any form of coronal preparation appears to be more beneficial for the apical region than preparation without coronal preparation.

In the present study, acrylic blocks were used, despite their physical differences from dentin tissue , as their transparent structure permits clear visualization of postoperative changes and allows for standardized reproduction of similar canal anatomies across samples (25). Considering the anatomical diversity in extracted teeth, standardization of samples with S-shaped canals is impossible in natural teeth. Nevertheless, it must be acknowledged that resin blocks have lower microhardness than dentin and are prone to thermal softening. Therefore, the clinical translation of these results should be interpreted with caution, as the actual transportation values in human teeth may deviate from those recorded in simulated blocks.

It has been reported that the use of different NiTi systems, either alone or in combination, in S-shaped canals may limit canal transportation (6,26,27). No significant transportation was observed in the apical constriction (0.5 mm) in any group, suggesting that the apical foramen was relatively preserved despite differences in the design and alloys of the coronal enlargement files.

The final apical file #25/.04 is preferred in our study, as ISO 25 is recommended as the final apical diameter for S-shaped canals (28). It has been reported in the literature that rotation-based systems create less transportation in the root canals compared to reciprocation-based systems (7,29). Therefore, to minimize the possible risks associated with reciprocation-based systems and to assess the effects of coronal enlargement files, a rotation-based system was preferred during final preparation.

Our results showed that the apical files were unable to adequately follow natural canal curvatures when cutting apically within narrow canal walls, leading to notable transportation. The degree of this transportation differed depending on the coronal file employed, and therefore, the null hypothesis is rejected. Moreover, coronal enlargement minimizes procedural errors by increasing the safety of preparation, especially in the apical region. This result, in accordance with literature studies, demonstrates that despite the advantages of rotary systems, the importance of coronal enlargement lies in decreasing the risk of transportation in S-shaped canals where the curve is bidirectional (27,30).

Conclusion

Based on the results of this study, various coronal enlargement files showed statistically significant differences in root canal transportation. The transportation of the apical constriction did not differ among the coronal preparation files; however, in the coronal region, more invasive and rigid files produced greater root canal transportation. For the apical curvatures, choosing any form of coronal preparation files seems to be beneficial.

The primary purpose of the hybrid combination is to leverage the advantages of file systems while minimizing their disadvantages as much as possible. Clinicians should balance the minimally invasive shaping with the highest disinfection by using a combination of various file systems rather than a single system, especially in curved root canals.

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ORIGINAL ARTICLE

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Knowledge and Attitudes of General Dentists, Endodontists, and Pedodontists Toward Regenerative Endodontic Treatment Protocols in Türkiye: A Cross-sectional Survey

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Purpose: This study aimed to investigate the knowledge and opinions of general dentists, pedodontists, endodontists, pedodontics and endodontic research assistants in Türkiye regarding regenerative endodontic treatment (RET) protocols for the necrotic immature teeth.

Methods: This survey-based study used an online platform and was administered on a voluntary basis. The first section included six demographic questions about participants' general characteristics. The second section consisted of 22 multiple-choice questions assessing the opinions and knowledge of general dentists, pedodontists, endodontists, and pedodontics assistants and endodontics research assistants regarding RET protocols.

Results: Statistically significant correlations across specialties ($p<0.05$) were found for responses to the following questions: "What was the source of your RET clinical protocol?", "In which situations do you prefer RET?", "How many visits do you complete RET?", "Which irrigation protocol method do you prefer for the first RET visit?", "Which method do you use for local anesthetic, irrigation solution, and scaffolding during the scaffolding visit?", "Which coronal barrier material do you use for RET?", and "What are the success criteria for RET?".

Conclusion: Variations in the application of RET protocols were observed among the branches examined. Specialists preferred this treatment more frequently and possessed more knowledge than general dentists.

Keywords: Endodontic treatment; regenerative endodontic treatment; scaffold; clinical protocol; tissue engineering.

Introduction

Technological advances have led to the replacement of traditional treatment approaches in dentistry with current and innovative methods. Regenerative endodontic therapy (RET), one of these methods, aims to restore vitality to traumatized, immature, and devitalized teeth by utilizing the regenerative potential of stem cells (1). Regenerative endodontics differs from traditional root canal treatment in that it aims to not only eliminate infection, but also repair and regenerate pulp tissue (2). This concept emerged

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in response to the limitations of traditional endodontic procedures in immature teeth, whose long-term prognosis is adversely affected by the loss of pulp vitality (3).

Root canal treatment, one of the most frequently applied traditional endodontic procedures, involves the removal of infected or necrotic pulp, disinfection of the root canal system, and filling with an inert filling material (4). Although this method is successful in many cases, it does not allow for the regeneration of functional tooth tissues because it cannot compensate for the loss of pulp tissue (3). RET aims to preserve the vitality of the pulp-dentin complex and support the regeneration of root structures. For this purpose, the regenerative capacity of stem cells, growth factors, and biocompatible scaffolds have been utilized (5). Growth factors play an important role in the regeneration process in the dental pulp. Molecules such as platelet-derived growth factor, transforming growth factor-beta, and vascular endothelial growth factor promote new tissue and vessel formation by regulating cell proliferation, differentiation, and angiogenesis (6,7). Additionally, biocompatible scaffolds facilitate tissue regeneration by providing three-dimensional support for cell attachment, proliferation, and differentiation (3). The clinical application of RET involves a series of steps aimed at creating a suitable microenvironment for tissue repair and regeneration (8). First, access is established to the root canal, removing bacteria and debris while preserving the existing living tissue. Bleeding is then induced, providing a source of endogenous growth factors and stem cells for the healing process. Finally, biocompatible scaffolds can be placed within the canal to promote cell attachment and proliferation (5,7).

Despite the promising results reported in the literature, there are ongoing debates regarding the clinical application of RET. Differences in treatment protocols, patient selection criteria, success assessment criteria, and lack of long-term follow-up data are the main reasons for this debate (9). In addition, the complexity of the root canal anatomy, presence of calcified interruptions, and possible changes constitute obstacles to the widespread use of RET (10). This study aimed to investigate the knowledge and opinions of general dentists, pedodontists, endodontists, and pedodontic and endodontic research assistants in Türkiye regarding RET protocols for the treatment of immature and necrotic teeth. We also compared the knowledge and practice of dentists with different specialties and experience levels regarding RET. Our null hypothesis is, "There is no significant difference between the RET application protocols and knowledge levels of dentists with different experience levels and specialties."

Materials and Methods

Ethical approval was obtained from the Non-Interventional Clinical Research Ethics Committee of Bolu Abant İzzet Baysal University (No: 2024/265; Date: 08/10/2024). This study was conducted in accordance with the principles of the Declaration of Helsinki.

Sample Size Calculation

The relationships between the answers to the questions in the main hypotheses of the study were investigated. In this study, the minimum sample size was calculated using G*Power 3.1.9.2 (G*Power 3.1.9.2; Heinrich-Heine-University Düsseldorf, Germany) (11) based on Cohen's effect size approach (12) and expert opinion. Although there are survey-based studies on RET in the literature, since the results reported in these studies did not provide directly usable effect size estimates for the multi-group comparisons in our analyses, the minimum sample size was set at 95 based on the assumptions of a standardized effect size of 0.50 (df=27), α=0.05, and power 0.80. A total of n=120 participants were ultimately included in the study.

This study was designed as a cross-sectional survey. Informed consent was obtained at the beginning of the surveys, which were prepared via an online platform (https://docs.google.com/forms) and administered on a voluntary basis. The survey link was distributed to general dentists, endodontists, pedodontists, and research assistants in related fields working in Türkiye via online platforms such as WhatsApp, email, and social media. To prevent multiple responses from the same person, the "Limit to 1 response" option was enabled on Google Forms. The first part of the survey included six demographic questions regarding the general characteristics of the participants (age, gender, specialization experience, program of graduation, institution of employment, participation in scientific congresses, seminars, or presentations), and the second part included 22 multiple-choice questions inquiring about the opinions and knowledge levels of general dentists, pedodontists, endodontists, pedodontics, and endodontic research assistants regarding RET protocols. Participants were not required to actively perform regenerative endodontic treatment (RET) to be included. Experience with RET was identified using the survey item 'Have you performed RET on your patients before?' (Yes/No). Based on the response, practice/protocol-related questions were displayed only to respondents who answered 'Yes'. The questionnaire was developed based on previous survey studies and guideline-based content. Before administration, the draft form was reviewed by five experienced clinicians for relevance, clarity, and comprehensiveness (content validity=1.00). Revisions were made according to their feedback, and the final version was then implemented.

Statistical Analysis

In this study, descriptive statistics (numbers and percentages) of the data are presented. To test the relationship between categorical variables, the Pearson Chi-Square test was applied when the sample size assumption (expected value >5) was met. When the sample size assumption was not met, Fisher's Exact test was used. The multiple chi-square test was used to analyze multiple-choice questions. Analyses were conducted using IBM SPSS version 27 (IBM, Armonk, NY, USA).

Results

Table 1 shows the demographic data and responses by branch. The distribution of answers to clinical questions by branch is presented in Table 2, and Pearson Chi Square, Fisher's Exact and Multiple Chi Square tests were used to examine the relationships between them. As a result of the analyses, statistically significant relationships were found between the answers to the questions "What was the source of your clinical protocol for RET?", "In which situations do you prefer RET?", "How many visits do you complete RET?", "What is your preference for the irrigation protocol in the first visit of RET?", "What is your preference for the local anesthetic, irrigation solution and scaffolding method in the scaffold visit?", "What is your preference for the coronal barrier material in RET?" and "What are the success criteria for RET?" according to the branches ($p<0.05$).

When the source of stem cells was questioned, endodontists most often indicated stem cells taken from the apical papilla (75%), whereas this rate was even higher among

Table 1. The distribution of branches according to their demographic characteristics and the relationships between them are given

	Endodontist		Pedodontist		Pedodontic		Research Assistant		Endodontic Research Assistant		General Dentist	
	n	%	n	%	n	%	n	%	n	%	Test Statistics	P Value
When did you graduate from dentistry school?												
Between 2000 and 2010	1a	12.5	2a	12.5	0a	0.0	0a	0.0	3a	9.7	47.855	<0.001*
Between 2011and 2020	6a,b	75.0	14b	8.5	11a	35.5	10a	29.4	10a	32.3		
After 2021	1a,b	12.5	0b	0.0	20a,c	64.5	24c	70.6	12a,c	38.7		
Before 2000	0a	0.0	0a	0.0	0a	0.0	0a	0.0	6a	19.4		
Age												
20-30	4a	50.0	10a,b	62.5	27a,b	87.1	31b	91.2	17a	54.8	24.093	<0.001*
31-40	3a	37.5	5a	31.3	4a	12.9	3a	8.8	6a	19.4		
>40	1a,b	12.5	1a,b	6.3	0b	0.0	0b	0.0	8a	25.8		
Gender												
Female	6	75.0	13	81.3	27	87.1	23	67.6	18	58.1	7.597**	0.108
Male	2	25.0	3	18.8	4	12.9	11	32.4	13	41.9		
Workplace												
University Hospital	4a	50.0	11a	68.8	31b	100.0	34b	100.0	2c	6.5	94.828	<0.001*
Oral and Dental Health Center	0a,b	0.0	1a,b	6.3	0b	0.0	0b	0.0	13a	41.9		
Special Clinic	4a	50.0	4a	25.0	0b	0.0	0b	0.0	16a	51.6		
What is your experience in your field?												
<1 year	0a,b	0.0	0b	0.0	15a	48.4	12a,b	35.3	5a,b	16.1	52.591	<0.001*
1-5 years	4a	50.0	9a	56.3	16a	51.6	20a	58.8	8a	25.8		
6-10 years	3a	37.5	5a	31.3	0b	0.0	2a,b	5.9	9a	29.0		
>10 year	1a,b	12.5	2a,b	12.5	0b	0.0	0b	0.0	9a	29.0		
How often do you attend scientific congresses, seminars or presentations related to your field?												
Once a year	2	25.0	4	25.0	11	35.5	19	55.9	9	29.0	19.454	0.058
Twice a year	4	50.0	3	18.8	5	16.1	7	20.6	5	16.1		
More than 2 times a year	1	12.5	7	43.8	4	12.9	5	14.7	9	29.0		
Less than once a year	1	12.5	2	12.5	11	35.5	3	8.8	8	25.8		

*p<0,05, ** Pearson Chi Square test, †Multiple Chi Square test, %: Column percentage and different letters indicate differences between row-wise column ratios.

Table 2. The distribution of answers to clinical questions by branch and the relationships between them are given

	Endodontist		Pedodontist		Pedodontic		Research Assistant		Endodontic Research Assistant		General Dentist	
	n	%	n	%	n	%	n	%	n	%	Test Statistics	P Value
What are the sources of stem cells in RET? (More than one option may be selected)												
Dental pulp stem cells	5a	62.5	8a	50.0	15a	48.4	26a	76.5	17a	54.8	68.046	<0.001*
Stem cells from human exfoliated deciduous teeth	2a	25.0	6a	37.5	13a	41.9	18a	52.9	8a	25.8		
Stem cells from the apical papilla	6a	75.0	15b	93.8	26b	83.9	26b	76.5	12a	38.7		
Dental follicle stem cells	2a	25.0	3a	18.8	15a	48.4	22b	64.7	9a	29.0		
Periodontal ligament stem cells	4a	50.0	7a	43.8	17a	54.8	24a	70.6	13a	41.9		
I don't know	1a	12.5	1a	6.3	1a	3.2	1a	2.9	8a	25.8		
Have you performed RET on your patients before?												
Yes	8a,b	100.0	15b	93.8	24a,b	77.4	18a	52.9	5c	16.1	41.742	<0.001*
No	0a,b	0.0	1b	6.3	7a,b	22.6	16a	47.1	26c	83.9		
Approximately how many RETs do you perform per year?												
1-3	6	75.0	4	26.7	8	33.3	13	72.2	3	60.0	14.552	0.181
4-10	2	25.0	7	46.7	6	25.0	3	16.7	1	20.0		
11-20	0	0.0	3	20.0	5	20.8	1	5.6	1	20.0		
>20	0	0.0	1	6.7	5	20.8	1	5.6	0	0.0		
What was the origin of the clinical protocol for RET?												
Individual study/literature research	4a	50.0	7a	46.7	12a	50.0	9a	50.0	2a	40.0	31.746***	0.046*
Protocol taught in specialization	6a	75.0	11a	73.3	20a	83.3	11a	61.1	3a	60.0		
Conferences and seminars	4a	50.0	10a	66.7	8ab	33.3	5b	27.8	4a	80.0		
Course	0a	0.0	1a	6.7	5a	20.8	1a	5.6	1a	20.0		
AAE Guideline	6a	75.0	9a	60.0	9b	37.5	16a	88.9	1a,b	20.0		
In which situations do you prefer RET? (More than one option may be selected)												
Teeth with open apex and necrotic pulp	8a	100.0	15a	100.0	24a	100.0	17a	100.0	4a	80.0	44.308***	0.001*
Closed apex teeth with necrotic pulp	2a	25.0	3a	20.0	2a	8.3	4a	23.5	2a	40.0		
Presence of periapical cyst	2a	25.0	1a	6.7	0a	0.0	1a	5.9	1a	20.0		
Presence of persistent periapical infection	2a	25.0	1a	6.7	1a	4.2	1a	5.9	2a	40.0		
Root resorption	5a	62.5	5b	33.3	1c	4.2	5b	29.4	1b	20.0		
Do you perform mechanical instrumentation on dentin walls in RET?												
Yes	3	37.5	0	0.0	3	12.5	2	11.1	1	20.0	8.552	0.312
No	5	62.5	11	73.3	18	75.0	12	66.7	3	60.0		
Sometimes	0	0.0	4	26.7	3	12.5	4	22.2	1	20.0		
How many visits do you prefer to complete the RET?												
1 visit	1a	12.5	0a	0.0	0a	0.0	1a	5.6	1a	20.0	11.347	0.043*
2 visit	6a,b	75.0	14a,b	93.3	24b	100.0	16a,b	88.9	3a	60.0		
More than 2 visits	1a	12.5	1a	6.7	0a	0.0	1a	5.6	1a	20.0		
What is your preference for the waiting period between visits in RET?												
1 week	0	0.0	2	14.3	1	4.2	1	6.3	1	33.3	14.882	0.148
2 week	1	16.7	7	50.0	9	37.5	6	37.5	1	33.3		
3 week	2	33.3	3	21.4	12	50.0	9	56.3	1	33.3		
4 week	3	50.0	2	14.3	2	8.3	0	0.0	0	0.0		
What is your irrigation protocol preference for the first visit of RET? (More than one option may be selected)												
NaOCl concentration >3.0%	0a	0.0	2a	14.3	4a	16.7	0a	0.0	1a	33.3	54.716***	0.007*
NaOCl concentration 1.5-3.0%	2a	33.3	3a	21.4	7a	29.2	3a	18.8	1a	33.3		
NaOCl concentration 1.5%	3a	50.0	11b	78.6	13a	54.2	12b	75.0	0a	0.0		
NaOCl concentration <1.5%	0a	0.0	2a	14.3	1a	4.2	1a	6.3	1a	33.3		
Chlorhexidine concentration 0.12%	0a	0.0	0a	0.0	0a	0.0	0a	0.0	1a	33.3		
Chlorhexidine concentration 2%	0a	0.0	0a	0.0	0a	0.0	0a	0.0	0a	0.0		
EDTA	2a	33.3	3a	21.4	4a	16.7	9b	56.3	1a	33.3		
Distilled water	2a	33.3	3a	21.4	2a	8.3	5a	31.3	0a	0.0		
Steril salin	3a	50.0	9a	64.3	15a	62.5	7a	43.8	1a	33.3		
What is your preference for intracanal medicament application in RET?												
Calcium hydroxide	4	66.7	13	92.9	17	70.8	16	100.0	3	100.0	19.585***	0.239
Double antibiotic paste	2	33.3	6	42.9	8	33.3	2	12.5	0	0.0		

Triple antibiotic paste	0	0.0	2	14.3	2	8.3	4	25.0	1	33.3		
Other	0	0.0	1	7.1	1	4.2	0	0.0	0	0.0		
What do you do if there are persistent symptoms of infection during RET?												
Application of a different intracanal medicament and follow-up	6	75.0	8	53.3	12	50.0	7	38.9	0	0.0		
Re-application of the same intracanal medicament and follow-up	1	12.5	4	26.7	8	33.3	9	50.0	3	60.0		
Termination of RET and transition to alternative treatment											9.746	0.249
Evaluation of other treatment options	1	12.5	3	20.0	4	16.7	2	11.1	2	40.0		
What is your local anesthetic preference for the scaffolding visit in RET?												
Vazokonstriktörlü lokal anestezik	1a	12.5	0a	0.0	0a	0.0	1a	5.6	5b	100.0	25.933	<0.001*
Local anesthetic without vasoconstrictor	7a	87.5	15a	100.0	24a	100.0	17a	94.4	0b	0.0		
What is your preferred irrigation solution for the scaffolding visit at RET? (More than one option may be selected)												
NaOCl concentration >3.0%	0a	0.0	0a	0.0	1a	4.2	0a	0.0	2b	40.0	67.844***	<0.001*
NaOCl concentration 1.5-3.0%	1a	12.5	1a	6.7	2a	8.3	0a	0.0	2b	40.0		
NaOCl concentration 1.5%	0a	0.0	3a	20.0	2a	8.3	2a	11.1	0a	0.0		
NaOCl concentration <1.5%	0a	0.0	1a	6.7	1a	4.2	1a	5.6	1a	20.0		
Chlorhexidine concentration 0.12%	0a	0.0	0a	0.0	1a	4.2	0a	0.0	1a	20.0		
Chlorhexidine concentration 2%	0a	0.0	1a	6.7	0a	0.0	0a	0.0	1a	20.0		
EDTA	7a	87.5	13a	86.7	22a	91.7	16a	88.9	2b	40.0		
Distilled water	2a	25.0	2a	13.3	1a	4.2	3a	16.7	0a	0.0		
Steril salin	3a	37.5	7a	46.7	15a	62.5	3a	16.7	2a	40.0		
What is your preferred method for scaffolding in RET?												
Inducing bleeding/blood clots	4a	50.0	15b	100.0	23b,c	95.8	6a	33.3	2a,c	50.0	34.517	<0.001*
Platelet-Rich Fibrin (PRF)	3a,b	37.5	0b,c	0.0	0c	0.0	9a	50.0	2a	50.0		
Platelet-Rich Plasma (PRP)	0a	0.0	0a	0.0	1a	4.2	2a	11.1	0a	0.0		
Other	1a	12.5	0a	0.0	0a	0.0	1a	5.6	0a	0.0		
What is your choice of coronal barrier material in RET? (More than one option may be selected)												
MTA	8a	100.0	15a	100.0	24a	100.0	9a	50.0	5a	100.0	52.232***	<0.001*
Biodentin	5a	62.5	7a,b	46.7	7b	29.2	15a	83.3	1a	20.0		
Endosequence root repair material	0a	0.0	0a	0.0	0a	0.0	0a	0.0	0a	0.0		
Other	1a	12.5	0a	0.0	0a	0.0	0a	0.0	0a	0.0		
What are the success criteria for RET? (More than one option may be selected)												
See apical closure	6a	75.0	15a	100.0	18a	75.0	14a	77.8	3a	60.0	39.360***	<0.001*
To detect thickening of dentin walls and root elongation	8a	100.0	15a	100.0	23a	95.8	18a	100.0	2b	40.0		
Getting answers to pulpal sensitivity and vitality tests	6a	75.0	11a	73.3	14a	58.3	12a	66.7	3a	60.0		
Ensuring that the tooth functions asymptomatically	7a	87.5	12a	80.0	20a	83.3	16a	88.9	3a	60.0		
What do you think are the challenges faced in RET? (More than one option may be selected)												
Difficulty in disinfecting the root canal in immature teeth	6	75.0	9	60.0	12	50.0	9	50.0	4	80.0	13.213***	0.868
Limited release of growth factors	4	50.0	7	46.7	12	50.0	9	50.0	2	40.0		
Difficulty of scaffolding application	4	50.0	6	40.0	14	58.3	9	50.0	3	60.0		
Inability to obtain sufficient numbers of autogenous cells	3	37.5	7	46.7	11	45.8	7	38.9	3	60.0		
Unpredictable outcome	6	75.0	11	73.3	22	91.7	12	66.7	2	40.0		
Do you think RET could be a practical and feasible alternative to a more aggressive treatment protocol?												
Yes	5	62.5	10	66.7	14	58.3	12	66.7	4	80.0	3.435	0.943
No	1	12.5	0	0.0	2	8.3	2	11.1	0	0.0		
Sometimes	2	25.0	5	33.3	8	33.3	4	22.2	1	20.0		
How much should RET cost?												
Less than alternative treatment	0	0.0	0	0.0	2	8.3	2	11.1	0	0.0	8.276	0.769
More than alternative treatment	5	62.5	11	73.3	14	58.3	11	61.1	4	80.0		
Equal to alternative treatment	1	12.5	3	20.0	7	29.2	5	27.8	1	20.0		
I'm undecided	2	25.0	1	6.7	1	4.2	0	0.0	0	0.0		

*p<0.05, ** Fisher's Exact test, †Multiple Chi Square test, %: Column percentage and different letters indicate the differences between row-based column ratios, RET: Regenerative Edndodontic Treatment. In questions where more than one option may be selected, the total of the column percentages by branches may exceed 100%.

pedodontists (93.8%). Among the pedodontics research assistants, the apical papilla was the most frequently preferred source (83.9%). Among endodontics research assistants, dental pulp stem cells (76.5%) and the apical papilla (76.5%) were the most frequently preferred sources, with similar rates. In general dentists, dental pulp stem cells (54.8%) and stem cells obtained from the periodontal ligament (41.9%) were more frequently preferred ($p<0.05$; Table 2).

The proportion of those who had previously performed RET was higher among endodontists (100%), pedodontists (93.8%), pedodontics research assistants (77.4%), and endodontics research assistants (52.9%) than among general dentists (16.1%). In contrast, the proportion of who had previously not performed RET was significantly higher in general dentists (83.9%) compared to other groups ($p<0.05$). Overall, 70 participants reported having performed RET, whereas 50 reported not having performed RET. Among respondents who had previously performed RET; 48.6% reported performing 1–3 cases/year and 10.0% reported >20 cases/year (Table 2).

When the source of clinical treatment protocols for RET was evaluated, the rate of pedodontics research assistants (33.3%) was higher than that of endodontics research assistants (27.8%) in the conference and seminar options. In the American Association of Endodontists (AAE) guideline option, the endodontics research assistant rate (88.9%) was significantly higher than the pedodontics research assistant rate (37.5%) ($p<0.05$; Table 2).

When evaluated in terms of their case preference for RET, the rate of endodontists (62.5%) for root resorption was higher than that of pedodontists (33.3%), pedodontics research assistants (4.2%), and endodontics research assistants (29.4%) ($p<0.05$; Table 2).

In terms of the preferred number of visits, the rates of pedodontics research assistants (100%), endodontics research assistants (88.9%), and pedodontists (93.3%) were higher than those of general dentists (60%) in the 2-visit option ($p<0.05$; Table 2).

When evaluated in terms of irrigation protocol preferences in the first visit of RET, the rate of pedodontists (78.6%) in the NaOCl 1.5% option is higher than the rate of endodontics research assistants (75%). In terms of EDTA use, the rate of endodontics research assistants (56.3%) is higher than the rate of pedodontists (21.4%). The rate of pedodontics research assistants preferring sterile saline (62.5%) was higher than the rate of endodontics research assistants (43.8%) ($p<0.05$; Table 2).

In the tissue scaffolding visit general dentists have the highest rate of local anesthetic with vasoconstrictor. In the option of local anesthetic without vasoconstrictor, the rate of pedodontists (100%) and pedodontics research assistants (100%) is similarly high as the rate of endodontics research assistants (94.4%) and endodontists (87.5%) ($p<0.05$; Table 2).

When irrigation solution preferences were evaluated during the tissue scaffolding visit in RET, the proportion of general dentists (40%) was higher than other dentists in the NaOCl concentration >3.0% and 1.5–3.0% option. In the EDTA option, the rates of endodontists (87.5%), pedodontists (86.7%), pedodontics research assistants (91.7%) and endodontics research assistants (88.9%) were higher than the rate of general dentists (40%). There are no statistically significant differences between branches in other solution options ($p<0.05$; Table 2).

When evaluated in terms of the method of tissue scaffolding in RET, the rate of pedodontists (100%) and pedodontics research assistants (95.8%) in the option of inducing blood clot is higher than other branches. The proportion of endodontics research assistants (50%) and general dentists (50%) using the platelet-rich fibrin (PRF) option was higher. The proportion of endodontics research assistants (11.1%) using the platelet-rich plasma (PRP) option was higher than the other groups ($p<0.05$; Table 2).

When the preference for coronal barrier material in RET was evaluated, mineral trioxide aggregate (MTA) was the most preferred material by all participants across groups. Biodentin preference was particularly high among endodontics research assistants (83.3%), while it was lower among pedodontics research assistants (29.2%) and pedodontists (46.7%). This rate was 20% among general dentists ($p<0.05$; Table 2).

When the success criteria for RET were evaluated, the highest rate of pedodontists (100%) was found to be in the option of seeing apical closure. In the option of detecting the thickening of the dentin walls and the continuation of root development, endodontists (100%), pedodontists (100%) and endodontics research assistants (100%), had the significantly highest rate ($p<0.05$; Table 2).

Discussion

This study investigated the knowledge and attitudes of general dentists, pedodontists, endodontists, and research assistants specializing in these two branches in Türkiye regarding RET protocols. The findings revealed that the majority of participants had basic knowledge of RET, but there were gaps in their knowledge of the protocols and implementation of existing guidelines. Additionally, significant differences in knowledge and practice were observed across different specialties. Pedodontists and endodontists,

in particular, were found to have higher awareness and experience than general dentists. These findings suggest that trends in Türkiye are consistent with the global literature (13-15).

When clinicians' experiences with RET are examined in the literature, the rate of those who stated that they had previously applied RET varies between 24.5% and 60% (14-16). Our findings are consistent with this range. Specialists who had previously performed RET were found to prefer this treatment at a higher rate than general dentists. Regarding the frequency of application among respondents who reported having performed RET (n=70), 48.6% reported performing 1–3 cases per year. In a survey of endodontists only, Lee et al. (17) reported that 60% of participants performed RET 1–3 times per year. In addition, 10% of the participants in our study reported performing RET more than 20 times per year. The difference between these studies may be due to the varying distribution of specialty fields within the sample.

Considerable variability in clinical protocols followed during RET has been reported in the literature (18). However, it is critical to follow a standard protocol to make clinical practice more predictable and widespread. In our study, more than half of the participants reported using the AAE guideline (19) as their primary source of protocols for RET. This finding is consistent with the findings of Hatipoğlu et al. (13) which included data from 13 countries. In the study in question, it was reported that the most frequently used source in RET applications was the AAE guide (19). In our study, when source preference was separated by branches, the rate of those who chose conferences and seminars as information sources was higher among pedodontics research assistants (33.3%) than endodontics research assistants (27.8%). On the other hand, the proportion of those using the AAE guideline as a reference was significantly higher in endodontics research assistants (88.9%) than in pedodontics research assistants (37.5%). This divergence may be due to differences in branch-specific educational contents and clinical experiences.

Recent advances in tissue engineering using stem cells isolated from teeth and surrounding tissues suggest that bioengineering approaches may enable the biological regeneration of not only specific dental tissues but also the entire tooth in the future (20). In this context, it is important to provide adequate knowledge and awareness among clinicians so that clinical practices can become widespread. Therefore, in our study, clinicians' knowledge levels regarding stem cells were evaluated. When the distribution by specialty was examined, the preference for apical papilla stem cells was 75% among endodontists, while this rate was 93.8% among pedodontists. Among pedodontics research assistants, the preference for apical papilla stem cells was 83.9%. In endodontics research assistants, dental pulp and apical papilla stem cells were each reported at a rate of 76.5%. In general dentists, it was observed that stem cells originating from dental pulp (54.8%) and periodontal ligament (41.9%) were labeled more frequently. These differences by specialty level may be due to the advanced biological knowledge provided in postgraduate education, the practical experience in RET, and the differences in focus of the educational content. The greater intensity of training in root development and apical regeneration processes, particularly in endodontics and pedodontics, explains the greater awareness and preference for apical papilla and dental pulp-derived stem cells in these disciplines.

It is reported that success in RET applications is related to making the correct diagnosis, selecting the appropriate case, and carefully determining the indications (19,21). In this context, our study evaluated the participants' views on case selection in detail. When the distribution by specialty was examined, it was found that the rate of root resorption indications was significantly higher among endodontists than among other specialties. In a case series published by Yoshpe et al. (22), RET was reported to be an effective and promising approach in stopping external root resorption. In addition, some case reports have reported that RET can be successfully applied in cases of internal root resorption (21). In this regard, the differences observed between branches are consistent with the fact that endodontists encounter root resorption cases more frequently in clinical practice and prefer RET procedures more frequently as a treatment approach. This finding suggests that the indications and patient range for regenerative procedures in endodontists may be wider than in pedodontists.

The AAE (19), generally recommends that RET be performed in two visits. According to this guideline, the first visit should include infection control and irrigation, while the second visit should include scaffold placement and application of the coronal barrier material. According to the findings of our study, clinicians in the fields of endodontics and pedodontics prefer two-visit treatment at a higher rate than general dentists. Similarly, Lee et al. (5) reported that single-visit RET can be applied in cases with partial pulp necrosis; and in cases with total pulp necrosis, multiple-visits RET can be completed by using intracanal medicament for intracanal disinfection. We believe that this difference observed between branches in our study is due to the fact that clinicians in specialties who received postgraduate education have more clinical experience and adherence to recommended guidelines.

The success of endodontic treatment depends primarily on the effective removal of bacteria and their toxins from

the root canal system (4). Since minimal instrumentation of the canals is advocated in RET, disinfection becomes difficult and therefore the use of intracanal medication is recommended (5). AAE and ESE guidelines recommend the use of calcium hydroxide or a combination of antibiotic paste as intracanal medication in RET (19,21). In this study, the majority of participants stated that they preferred calcium hydroxide as an intracanal medicament. This finding is parallel to the results of the study conducted by Hatipoğlu et al. (13) in 13 countries. Factors such as lower cost, easier manipulation, lower cytotoxicity, and the ability to provide effective intracanal disinfection without causing coronal discoloration compared to antibiotic paste combinations may have played a role in clinicians' preference for calcium hydroxide.

The choice of irrigation solution in root canal treatment is one of the most critical steps that directly impacts the success of the treatment. In RET applications, this choice is even more crucial because of its impact on stem cell viability and tissue regeneration (18). It has been reported in the literature that irrigation with high concentrations of NaOCl during RET negatively affects the survival and differentiation of apical papilla stem cells (3,23). However, it has been reported that this adverse effect can be prevented by using 1.5% NaOCl followed by 17% EDTA (23). When the clinicians' irrigation protocol preferences were examined in our study during the first RET visit, the rate of 1.5% NaOCl use was slightly higher among pedodontists (78.6%) than among endodontics research assistants (75%). On the other hand, another study conducted in Türkiye reported that endodontists and pedodontists use 2.5% NaOCl at higher rates (14). When EDTA use was evaluated in the first visit, the rate of endodontics research assistants (56.3%) was found to be higher than that of pedodontics research assistants (21.4%). In terms of preference for sterile saline, the rate of pedodontics research assistants (62.5%) was higher than that of endodontics research assistants (43.8%). However, sterile saline has no direct effect on disinfection or stem cell differentiation. Therefore, it is recommended to use it only as the final irrigation solution after 17% EDTA to minimize cytotoxic effects (19,21). Irrigation with EDTA has been shown to release growth factors from dentin tissue, promoting the survival and differentiation of odontoblastic stem cells (23). Therefore, guidelines recommend using a combination of EDTA and saline as the final irrigation solution at each visit (19,21). Based on the responses obtained in our study, clinicians' irrigation solution preferences appear to be generally consistent with the guidelines.

When clinicians' irrigation solution preferences were evaluated during the tissue scaffolding visit, it was considered a striking finding that general dentists' use of NaOCl at concentrations of 1.5–3.0% and higher than 3% was higher compared to other branches. Similarly, in a study conducted in Türkiye, it was observed that most participants preferred minimal instrumentation and generally used high concentrations of NaOCl as an irrigation solution (14). In a study conducted in 13 countries by Hatipoğlu et al. (13), it was reported that clinicians had different irrigation solution preferences at this stage. AAE and ESE clearly recommend avoiding the use of NaOCl completely at the scaffolding stage as it may inhibit the attachment of stem cells to dentin and reduce dentin-derived growth factors (19,21). Despite this, some participants appear to prefer NaOCl for greater disinfection. The findings suggest that there is significant variability in irrigation protocols and that clinicians worldwide are still not fully adhering to current guideline recommendations.

When the preference for tissue scaffolds in the RET protocol is questioned, it is observed that pedodontist and pedodontics research assistant prefer bleeding induction at a higher rate than other branches. In parallel with this finding, a study conducted in England reported that 75% of pedodontists and pedodontics research assistants preferred blood clot as a scaffold (24). The possible reason for the limited use of alternative tissue scaffolds such as PRF or PRP in pedodontics clinics is the difficulty of collecting blood from children and the fact that this procedure can lead to behavioral disorders towards other dental treatments. Therefore, considering the limitations of other clinically applicable biological scaffold options, controlled bleeding induction in the root canal remains the most practical and effective method for transporting the stem cell population into the canal system, demonstrating a three-dimensional organization there, and supporting the regenerative process (18,25). In contrast to this situation, a study by Tong et al. (26) found an increase in the use of tissue scaffolds other than bleeding induction by pedodontic specialists. Similarly, the use of alternative tissue scaffolds (PRF, PRP) has become increasingly popular in recent years, as can be seen in the literature (27). In fact, in this survey study, general dentists, endodontists and endodontics research assistants stated that they use PRF or PRP at a high rate. Additionally, various studies have shown that the use of PRF and PRP has similar effects on blood clots in terms of clinical outcomes (28). When bleeding cannot be induced in other branches in adult patients, the reason for preferring alternative scaffolds may be the easier collection of intravenous blood samples from adult patients.

Another important issue related to the induction of bleeding is the choice of local anesthetic solution used in the scaffolding visit. The AAE (19), recommends the use of

3% mepivacaine without a vasoconstrictor to induce bleeding. This suggestion is also in line with the results of the study conducted by Petrino et al. (29). Similarly, in our study, it was determined that the majority of clinicians in the field of endodontics and pedodontics preferred local anesthetics that did not contain vasoconstrictors, whereas only general dentists used local anesthetic solutions with vasoconstrictors. We believe that this difference may be due to general dentists' lack of knowledge about RET practices, their inadequate clinical experience, and their inadequate follow-up of current guidelines.

MTA was found to be the most preferred coronal filling material across all survey groups. This finding is consistent with other studies reported in the literature (18,26). However, Biodentin preference was found to be higher among endodontics research assistant compared to other branches. The bismuth oxide in MTA can cause coronal discoloration, causing aesthetic problems for patients (30). This situation may have directed clinicians to use Biodentin to prevent possible aesthetic problems. Contrary to these findings, a study reported that different coronal barrier materials, not MTA and Biodentin, were used in Arab countries (26). These differences in the clinician's choice of material may be due to the ease of access to the material used and the current conditions of the clinic where treatment is administered.

The success of RET depends on achieving biological goals, such as elimination of infection, maintenance of root development, thickening of root canal walls, and resensitization of pulpal tissue (5). However, the literature reports significant differences between the clinical protocols applied to achieve these goals (13,14). Among the success criteria determined in our study, it was observed that the participants preferred high apical closure, dentin wall thickening, root elongation, pulp sensitivity/vitality response, and asymptomatic tooth function. These data are generally consistent with results reported in similar studies (20,26,31). In contrast, when evaluating the responses across specialties, it was observed that pedodontists prioritized "observation of apical closure," whereas endodontists prioritized "dentinal wall thickening and root lengthening". We believe that these differences may stem from variables such as the survey participant profile, specialized training processes of the specialists, clinical experience, and the case in which treatment was administered.

This study had several limitations. Since the data were collected through a survey, they reflect subjective evaluations; the sample size and distribution may not represent all experts, and the sample sizes among specialties are not balanced; some subgroups have relatively small samples (for example, the endodontist group n=8); therefore, the results should be interpreted with caution in terms of the generalizability of the findings. In addition, test–retest reliability and internal consistency (e.g., Cronbach's alpha) were not assessed, as the questionnaire consisted of heterogeneous knowledge and practice items rather than a single psychometric scale. Furthermore, the lack of objective clinical and radiographic data makes it difficult to assess long-term success. The widespread adoption of RET in pedodontics and endodontics requires time, appropriate infrastructure, and a systematic plan. Additional research and support for specialty-specific continuing education programs may facilitate the integration of RET into clinical practice.

Conclusion

Limited evidence regarding the long-term success of RET has led physicians to be cautious regarding its use. It is anticipated that RET will be more widely and safely implemented with increased training programs, adherence to international guidelines, and standardization of clinical protocols.

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ORIGINAL ARTICLE

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Language-Dependent Accuracy of Large Language Models in Dental Avulsion Scenarios: A Comparative Study

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Purpose: To evaluate whether the accuracy of responses generated by large language model–based systems to dental avulsion–related questions differs according to language.

Methods: Dental avulsion questions based on International Association of Dental Traumatology guidelines were administered to ChatGPT (version 5.1) and Meta AI in Turkish and English. Queries were submitted using two independent user accounts over seven consecutive days. All responses were restricted to a true–false format and assessed for guideline compliance. Paired comparisons were performed using the McNemar test.

Results: A total of 2,800 responses were analyzed. ChatGPT showed comparable accuracy in Turkish and English. In contrast, Meta AI demonstrated higher accuracy in English than in Turkish. When compared under identical conditions, ChatGPT exhibited higher overall accuracy, primarily due to differences in Turkish responses.

Conclusion: Language may influence the performance of large language model–based systems in dental avulsion scenarios in a model-dependent manner, underscoring the need to consider linguistic factors when evaluating AI-generated clinical information.

Keywords: Artificial ıntelligence; dental trauma; endodontics; tooth avulsion.

Introduction

Avulsion of permanent teeth is a severe traumatic condition that accounts for approximately 0.5–16% of dental injuries and is considered one of the most serious forms of dental trauma (1). Numerous studies in the literature have demonstrated that the prognosis of dental avulsion largely depends on the quality of the immediate first aid provided at the site of injury and the clinical management implemented during the early post-traumatic period (2,3). Although replantation is considered the primary treatment option in most cases, it cannot always be performed immediately due to various clinical and environmental conditions. Therefore, the adoption of appropriate emergency management strategies and the development of an individualized treatment plan play a decisive role in achieving favorable clinical outcomes.

In recent years, rapid advances in digital technologies have markedly increased the use of artificial intelligence (AI)–based applications in dental education, clinical decision support systems, and patient–clinician communication. Among these applications, AI-driven conversational chatbots based on natural language processing algorithms

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have gained increasing prominence due to their ability to interact with users, provide guidance, and generate educational content. (4). Chatbots offer innovative applications in healthcare by enabling rapid access to information, supporting educational processes, and facilitating user guidance (5). Among the chatbot platforms widely used in the healthcare domain today are ChatGPT, Gemini, Microsoft Copilot, Perplexity, and Claude. These conversational systems have been reported to support the accessibility of evidence-based information, reduce clinicians' workload, and provide timely responses to patient inquiries.

Chat Generative Pre-trained Transformer (ChatGPT®), developed within this context, is defined as an advanced large language model trained using natural language processing and deep learning algorithms, capable of simulating human–computer interaction through text-based communication (6). ChatGPT has been trained on large-scale datasets derived from open-access digital sources, academic publications, and books, enabling it to generate text, perform multilingual translation, and provide contextually appropriate responses to user queries (7). Nevertheless, reliance on online sources for information generation may entail certain limitations, including potential biases present in web-based educational content and constraints related to the level of detail provided. (8).

Meta AI is a general-purpose artificial intelligence assistant developed by Meta Platforms and integrated into Meta's online services. The system is built upon Meta's large language model family, the Large Language Model Meta AI (LLaMA) architecture, and is capable of generating natural language responses across a wide range of topics (9). Although Meta AI is designed as a general-purpose system intended to provide information and interactive assistance to a broad user base, scientific studies evaluating its performance in clinical scenarios within the fields of medicine and dentistry remain limited. The paucity of studies systematically examining Meta AI's accuracy of health-related information, adherence to clinical guidelines, or language-dependent performance differences underscores the need for further research assessing the responses generated by such systems, particularly in acute clinical contexts.

Within the scope of this study, the accuracy of responses provided by large language models in Turkish and English was comparatively evaluated. In the existing literature, the performance of AI-based chatbots has predominantly been assessed in a single language, while studies directly examining the impact of linguistic differences on the clinical information generated by these systems remain limited (10,11). Accordingly, the present study aimed to evaluate how the accuracy of responses and adherence to current clinical guidelines provided by ChatGPT 5.1 and Meta AI to dental avulsion–related questions vary according to language (Turkish versus English). Responses generated in Turkish and English were systematically compared to provide a comparative assessment of the information-generation performance of these chatbots in acute clinical situations such as dental avulsion. To the best of our knowledge, this study is among the first to comparatively investigate the effect of language on the accuracy of responses generated by AI-based chatbots in dental avulsion scenarios. Accordingly, the null hypothesis of this study was that there would be no significant difference in the accuracy of responses generated by AI-based chatbots according to language (Turkish versus English) or between different chatbot systems under identical conditions.

Materials and Methods

Ethical considerations

This study did not involve human participants or patient data; therefore, approval from an institutional ethics committee was not required. All data analyzed in the study consisted exclusively of outputs generated by artificial intelligence–based systems.

Development of clinical questions

This observational, comparative study was designed to evaluate the accuracy of responses provided by AI-based chatbots to dental avulsion scenarios and to assess the effect of language differences (Turkish versus English) on response accuracy. Clinical questions related to dental avulsion were developed based on the most recent guidelines published by the International Association of Dental Traumatology (IADT) (12).

The question set was formulated by two academicians in the field of endodontics with different academic ranks (MG and HSO) and was structured to cover clinically critical domains, including emergency management, first aid measures, replantation conditions, storage media, and follow-up strategies. Evaluation of the chatbot responses was conducted with blinding to both the chatbot identity and the language of the responses.

All questions were initially prepared in Turkish and subsequently translated into English using a literal (one-to-one) translation approach. To ensure semantic equivalence, the Turkish and English versions were compared in terms of content and phrasing and finalized accordingly. The complete list of questions used in the study is provided in the Appendix.

AI models and prompting procedure

Two different AI-based chatbot systems were evaluated in

this study: ChatGPT (version 5.1) and Meta AI. To enhance response diversity and reproducibility, all queries were conducted using two independent user accounts (EA and GY). Each user submitted the same set of questions to both chatbot systems twice daily (morning and evening) over seven consecutive days between November 29 and December 5, 2025. This querying strategy was determined based on methodological approaches adopted in previous studies employing similar designs (13,14). Each question was posed in a separate and new chat session. To prevent contextual carryover between questions, the chat history was cleared prior to each query, thereby minimizing the potential influence of previous responses on subsequent outputs.

To standardize the response format and ensure objectivity in the evaluation process, a specific instruction was provided to the chatbots before posing the English questions: "I will now ask you a question. Please respond only with 'True' or 'False'. Do not provide any explanation."

The same instruction was applied to the Turkish questions using semantically equivalent wording. This approach was adopted to obtain all responses in a binary and directly comparable format. All questions were presented to each chatbot in both Turkish and English using identical phrasing, and the resulting responses were recorded without any modification or intervention.

Data collection and outcome definition

All responses generated by the chatbots were transferred to a Microsoft Excel spreadsheet for data management and analysis. Each response was evaluated for compliance with the IADT guidelines (12) and coded in a binary manner as correct (1) or incorrect (0). This coding approach enabled the quantitative determination of accuracy levels for each chatbot and for each language. In the evaluation of the responses, the recommendations provided in the IADT guidelines were accepted as the primary reference.

The chatbot queries were administered by two independent users (EA and GY), who recorded all responses in a binary format (true/false) based on a predefined answer key. The clinical questions and the corresponding reference answers, developed in accordance with the IADT guidelines, were prepared in advance by an experienced endodontist (MG). Using this reference framework, EA and GY classified the chatbot responses as correct or incorrect. The coded data were subsequently transferred to MG for statistical analysis. Throughout the entire process, blinding was maintained with respect to both the chatbot identity and the response language. As the classification of chatbot responses was based on a predefined reference answer key, no independent subjective assessment was required, and therefore no consensus or disagreement resolution procedure was applicable.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics software (version 30.0; IBM Corp., Armonk, NY, USA). Accuracy rates were calculated separately for each chatbot (ChatGPT version 5.1 and Meta AI) and for each language (Turkish and English).

To evaluate the effect of language on response accuracy, Turkish and English responses corresponding to the same question set were treated as paired observations. Accordingly, language-based comparisons were conducted using the McNemar test. Similarly, under identical conditions, the performance of ChatGPT 5.1 and Meta AI was analyzed as paired categorical data, and comparisons between the two chatbot systems were also performed using the McNemar test.

In cases where cell frequencies were low and the assumptions of asymptotic methods were not met, the exact version of the McNemar test was applied. All statistical analyses were two-tailed, and a p-value of <0.05 was considered statistically significant.

Results

A total of 2,800 responses were analyzed in the study. Each chatbot generated 1,400 responses in total, comprising 700 responses in Turkish and 700 responses in English. Accuracy rates were calculated separately for each chatbot and language.

Overall accuracy differed across chatbot systems and languages (Table 1). ChatGPT demonstrated consistently high accuracy in both Turkish and English, whereas Meta AI showed comparatively lower accuracy, particularly for Turkish responses.

Paired comparisons revealed no statistically significant language-related difference in response accuracy for ChatGPT. In contrast, Meta AI exhibited a significant language-dependent difference, with higher accuracy observed for English responses compared with Turkish responses (Table 2).

When chatbot performance was compared under identical conditions, ChatGPT demonstrated significantly higher overall accuracy than Meta AI. Language-specific analyses indicated that this difference was driven primarily by Turkish responses, while no significant difference was observed between the two chatbots for English responses (Table 2).

Table 1. Accuracy of chatbot responses by language

Chatbot	Language	Correct (n)	Total (n)	Accuracy (%)
ChatGPT 5.1	English	682	700	97.4
ChatGPT 5.1	Turkish	672	700	96.0
Meta AI	English	675	700	96.4
Meta AI	Turkish	664	700	94.9

Accuracy values are presented as percentages of correct responses.

Table 2. Pairwise comparisons of chatbot response accuracy

Comparison	p-value
ChatGPT: Turkish vs English	0.154
Meta AI: Turkish vs English	0.018*
ChatGPT vs Meta AI (Overall)	0.021*
ChatGPT vs Meta AI (Turkish)	0.048*
ChatGPT vs Meta AI (English)	0.296

Paired comparisons were performed using the McNemar test. The exact McNemar test was applied when cell frequencies were low.

Discussion

In this study, the accuracy of responses generated by artificial intelligence–based conversational systems was comparatively evaluated in Turkish and English within the context of dental avulsion, a topic of critical clinical relevance. The findings demonstrated that ChatGPT exhibited consistent accuracy levels across both languages, indicating that language did not have a statistically significant effect on response accuracy for this model. In contrast, a marked language-dependent difference was observed in the performance of Meta AI, with responses provided in English showing significantly higher accuracy than those generated in Turkish. Taken together, these results suggest that large language models may display language-dependent variability in the generation of clinical information, and that the extent of this effect may vary across different models. Accordingly, the null hypothesis was partially rejected based on the present findings.

Artificial intelligence–based chatbots have attracted increasing interest in dental research due to their potential to provide rapid access to clinical information and to present up-to-date scientific content. Developed on the basis of natural language processing techniques and large language models, these systems are capable of sharing information related to clinical guidelines and treatment protocols with users. Nevertheless, the accuracy and scientific reliability of the responses generated by such models remain important issues that continue to be debated in the literature (15). Existing studies indicate that chatbots such as ChatGPT may exhibit heterogeneous performance in terms of information accuracy and content quality (16,17). In this context, the systematic evaluation of the accuracy of information provided by artificial intelligence–based systems is of particular importance, especially in emergency clinical situations that may directly influence patient management. Moreover, due to their generative nature, these systems may occasionally produce inaccurate information or content that is not fully aligned with clinical guidelines, further underscoring the need for human oversight and content verification in emergency clinical decision-making processes (18).

The multilingual communication capacity of artificial intelligence–based systems is becoming an increasingly decisive factor in the digital transformation of global healthcare services. The ability to effectively reach patient populations with diverse linguistic and sociocultural backgrounds directly influences the effectiveness of health communication, particularly in an era marked by the widespread use of digital information sources. Within this framework, evaluating the performance of responses generated by AI-based chatbots across different languages is important not only for ensuring the accuracy of clinical information, but also for facilitating correct interpretation of the information by users. Turkish was included in the evaluation as it is the primary language widely used in clinical and everyday communication in the country where the study was conducted. English, on the other hand, is widely recognized as the common language of international academic and clinical communication in the health sciences. Posing the questions in both languages enabled a comparative assessment of language-dependent variations in chatbot performance.

In this study, the most up-to-date version of ChatGPT that was accessible during the study period was used. This choice was intended to allow the evaluation of the model's current capabilities in context management and response generation. Meta AI, a LLaMA-based artificial intelligence assistant developed by Meta Platforms, was included in the evaluation as a system representing broad user interaction, given its integration into widely used platforms such as

WhatsApp, Instagram, and Facebook (19). This approach enabled a comparative evaluation between an artificial intelligence system that is widely used in the literature and an alternative system that reflects everyday real-world usage scenarios.

In the study conducted by Büyüközer Özkan et al. (20), the evaluation of ChatGPT responses revealed that answers generated in English demonstrated significantly higher accuracy compared with those provided in response to questions posed in Turkish In contrast, the present study did not identify a statistically significant difference in the accuracy of ChatGPT responses between Turkish and English. However, when the Meta AI model was evaluated, findings similar to those reported by Büyüközer Özkan et al. (20) were observed, with responses generated in English demonstrating higher accuracy than those provided in Turkish. This discrepancy may be related to differences in the scope and nature of the clinical topics addressed in the two studies. While the study by Büyüközer Özkan et al. (20) primarily focused on regenerative endodontics, a field that requires interpretation of conceptual knowledge, biological processes, and treatment principles, the present study addressed dental avulsion, a condition characterized by more clearly defined clinical protocols and guideline-based management. These observations suggest that language-dependent performance differences may be influenced not only by the language used or model-specific characteristics, but also by the nature of the clinical topic and the type of knowledge involved. Accordingly, evaluations of the linguistic performance of AI-based systems should also take topic-specific content dynamics into consideration.

Turkish poses significant challenges for natural language processing systems due to its agglutinative structure and complex morphological characteristics (21,22). It has been reported that agglutinative languages may exhibit lower performance in language models compared with inflectional languages, a phenomenon that may be associated with the English-centric design of tokenization methods and the limited representation of language-specific patterns unique to Turkish in training datasets (22,23). Büyüközer Özkan et al. (20) attributed the lower success rate observed in Turkish responses compared with English in ChatGPT outputs to these linguistic and structural characteristics (20).

In a study by Şimşek and Kurt, which is currently in press, it was reported that the readability, quality, and reliability of information provided by artificial intelligence–based chatbots may be sensitive to language (24). These findings, in line with the results of the present study, suggest that linguistic variables may influence the performance of certain artificial intelligence–based systems.

The cross-lingual evaluation framework proposed by Jin et al. demonstrated that large language models in the healthcare domain may exhibit lower performance in languages other than English (11). The findings of the present study conceptually align with this general trend, while additionally providing a complementary contribution to the literature by demonstrating that the linguistic effect may be model-specific.

In the bilingual, examination-based study conducted by Wójcik et al., no language-related difference in accuracy was identified for the ChatGPT-4 and Claude models, whereas Gemini was reported to demonstrate higher accuracy in English responses compared with those provided in Polish (10). This finding is consistent with the language-dependent performance differences observed for the Meta AI model in the present study and supports the notion that the impact of language may vary in a model-specific manner.

The absence of a significant difference between ChatGPT's Turkish and English responses in the present study suggests that the model's language generalization capabilities may yield more balanced outcomes in certain clinical scenarios. In contrast, the language-dependent performance disparity observed for Meta AI, particularly the relatively lower accuracy of its Turkish responses, indicates that the modeling of procedural information in morphologically rich languages may be influenced by model-specific limitations. Furthermore, the finding that accuracy differences between the two models were primarily evident in Turkish responses, while no significant difference was detected for English outputs, suggests that the English-centric training structures of large language models may contribute to more consistent performance in English. In this context, the evaluation of artificial intelligence models in clinical dental applications should consider not only overall accuracy rates but also the combined interaction of language, clinical topic, and model characteristics.

This study has several limitations that should be acknowledged. First, the analysis was restricted to two artificial intelligence systems, namely ChatGPT 5.1 and Meta AI, and therefore the findings cannot be generalized to other large language models. In addition, the comparison was conducted using specific clinical scenarios and predefined question sets; other endodontic topics or broader clinical contexts were not included in the evaluation. The questions used in the study were limited to a true–false format, and open-ended questions or those requiring clinical decision-making were not assessed. This may have limited a comprehensive evaluation of the models' capacity to generate responses involving more complex reasoning and

explanatory depth. Linguistic performance was confined to Turkish and English, and other morphologically rich languages were not examined. Another limitation of this study is that response consistency across repeated queries was not separately analyzed. This approach was intentional, as the primary aim was to assess language-related differences in response accuracy and guideline adherence, rather than the consistency of chatbot responses over time. Finally, given the rapidly evolving nature of artificial intelligence models, it should be considered that the versions evaluated in this study may have been replaced by more recent iterations during the publication process.

Conclusion

The findings of this study suggest that language may influence the performance of large language model–based systems in acute dental trauma scenarios in a model-dependent manner. Accordingly, the evaluation and clinical integration of such systems should consider linguistic factors alongside model characteristics, particularly in non-English contexts. Further research is warranted to better define the reliability of AI-generated clinical information across languages and clinical domains.

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ORIGINAL ARTICLE

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Evaluation of the Relationship Between Interorificial Distance and Internal Root Canal Anatomy of Mandibular Incisors Using Cone-Beam Computed Tomography

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Purpose: This study aimed to evaluate the relationship between the interorificial distance (IOD) and buccolingual distance (BLD) in mandibular incisors with two canals and apical termination, along with demographic (age and gender) and anatomical factors (number of canals and Vertucci classification) in the Turkish subpopulation using cone beam computed tomography (CBCT).

Methods: High-quality CBCT scans of patients with all mature mandibular incisors present and without previous endodontic treatment, root resorption, calcification, cracks, fractures, or restorations were screened in terms of demographic data, Vertucci canal configurations, IOD, BLD, and apical termination types. Data were statistically analyzed.

Results: A total of 1344 mandibular incisors from 336 patients were analyzed, revealing that 25% had two canals, with no significant differences by gender, age, or tooth side. The most common canal configuration was Vertucci Type I, while Types III and II were mainly found in teeth with two canals. BLD decreased significantly with age ($p<0.05$). The BLD/IOD ratio was significantly decreased in teeth with two distinct apical foramina ($p<0.05$). A significant positive correlation was found between BLD and IOD ($p<0.05$).

Conclusion: The correlation between BLD and IOD offers a practical reference for predicting canal configurations, while the differences in apical termination types highlight the need for tailored clinical approaches. Understanding these anatomical variations is crucial for achieving optimal outcomes.

Keywords: Canal configuration; cone beam computed tomography; endodontics, mandibular incisors; vertucci classification.

Introduction

The success of endodontic treatment relies upon the precise identification, disinfection, and hermetic obturation of the root canal system (1). A comprehensive understanding of root canal anatomy, including canal number and configuration, is crucial for achieving optimal treatment outcomes (2). In this sense, unidentified canals jeopardize chemomechanical disinfection since they harbor microorganisms and by-products (3). Consequently, untreated

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or missed root canals can increase the risk of developing periapical pathology, adversely affecting the long-term prognosis (4).

Various methods have been employed over time to study root canal morphology, including canal staining and clearing techniques (5,6), macroscopic and histological sectioning (7), conventional two-dimensional radiographic imaging (8), micro-CT (9), cone-beam CT (CBCT) (10,11), and dental operating microscopes in order to minimize the diagnosis-based complications. In this sense, the use of CBCT has become increasingly popular in endodontic diagnosis due to its several advantages, such as short exposure time, lower cost compared to conventional CT, high resolution, three-dimensional imaging capability, and non-invasiveness (12-15). Accordingly, the CBCT position of the statement of AAE has also stated that CBCT does have a place in endodontic diagnosis when dealing with complex cases (16).

Mandibular incisors are the smallest teeth in the permanent dentition (17). Typically, they have two canals oriented buccolingually with complex root canal anatomy (18). Due to their diminutive size and complex internal morphology, these teeth present significant challenges in the preparation of access cavities (19). Especially, the majority of endodontic failures in mandibular incisors are attributed to the presence of an undetected lingual canal due to the narrow canal orifice (20). Given these anatomical complexities, a precise understanding of the spatial relationship between the buccal and lingual canals is crucial for achieving successful endodontic outcomes.

Although the root canal anatomy of mandibular incisors has been investigated previously (2,12,18,21), the interorificial distance (IOD) between canals and its potential associations with demographic and anatomical factors have not been thoroughly explored in the Turkish subpopulation. Since IOD is a critical parameter that could influence access cavity design and endodontic instrumentation, evaluating its relationship with other morphological parameters remains an area of ongoing interest, particularly in the context of individualized treatment planning. In addition, evaluating possible relationships could also contribute valuable insights to enhance the accuracy of diagnosis, improve treatment outcomes, and provide a better understanding of mandibular incisor morphology in clinical practice. Thus, this study aimed to evaluate the relationship between the IOD and buccolingual distance (BLD) in mandibular incisors with two canals and apical termination, along with demographic (age and gender) and anatomical factors (number of canals and Vertucci classification) in the Turkish subpopulation using CBCT. Based on this aim, the primary null hypothesis was posited that the BLD, IOD, and BLD/IOD values would not differ based on apical termination.

Materials and Methods

This study was conducted following approval from the Scientific Research Ethics Committee of the University of Health Sciences (Date: 26/09/2023, No: 2023-337) and according to Declaration of Helsinki.

The CBCT archive records of the Department of Oral and Maxillofacial Radiology of the University of Health Sciences, spanning the period from January 2022 to December 2023, were scanned in the scope of this study. The data comprises CBCT images obtained during the diagnostic and treatment planning stages for patients undergoing pre-treatment evaluations for implant placement or orthodontic therapy without any special attempt to perform this study. Moreover, patient identity information was not accessed during analysis.

The following inclusion criteria were applied during the selection: Presence of all mandibular incisors, incisors with complete root development, incisors without pathological alterations and history of endodontic treatment, absence of root resorption, calcification, or other structural abnormalities, artificial crowns or post–core restorations, and high-quality CBCT scans suitable for anatomical assessment. Accordingly, 502 CBCT records were screened, and 336 patients meeting the inclusion criteria were included in the final sample.

All CBCT images were acquired using a CBCT device (J Morita Mfg. Corp., Kyoto, Japan) operating at 80 kV and 2.0 mA, with an exposure time of 15.5 seconds. The voxel size was set to 0.25 mm, the slice thickness was 1 mm, and the field of view (FOV) was 140×100 mm. All CBCT images were obtained using the same standardized imaging parameters for all patients. All scans were captured by an experienced radiology technician in accordance with the manufacturer's recommended protocol, ensuring adequate image quality while minimizing exposure and radiation dose.

The CBCT images of patients were examined independently by a radiologist (xx) and an endodontist (yy) on an HP Compaq LE1711 LCD monitor (Palo Alto, CA, USA) using the device's proprietary i-Dixel software, in a dimly lit room, at a distance of approximately 50 cm from the screen. In the event of any discrepancies, a third evaluation was carried out by an additional endodontist and radiologist (xx and yy) to facilitate consensus and ensure accurate assessment.

The selected scans of patients were evaluated regarding demographic and morphological details. Accordingly, gender (female-male), tooth side (right-left), and age (Group 1: 17-35 years, Group 2: 36-55 years, Group 3: >55 years) information were recorded. In terms of morphological

assessment, the canal configurations of the right and left mandibular incisors were classified according to Vertucci's criteria (22). Moreover, the BLD and IOD were measured on axial view (23,24). While the BLD refers to the buccolingual distance measured on an axial section obtained at the first level where both the buccal and lingual canals are simultaneously visible, the IOD describes the distance between buccal and lingual canals at the same view (Fig. 1).

Mandibular incisors were further assessed regarding apical termination. In this sense, teeth were classified as follows: Type A: Buccal and lingual canals merge before exiting at a single apical foramen, and Type B: Buccal and lingual canals remain separate and exit through two distinct apical foramina (22,25).

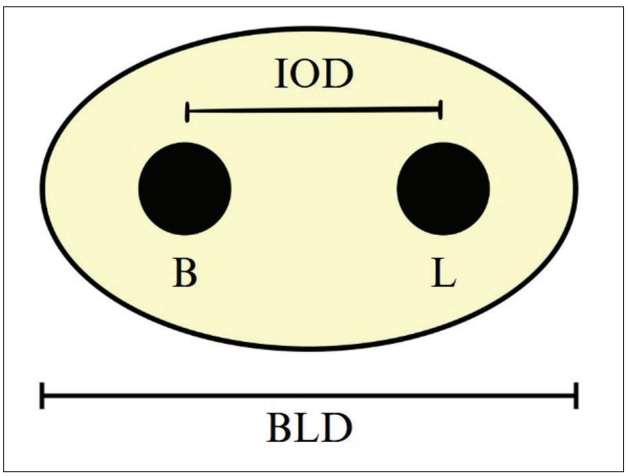

Fig. 1. Measurement of buccal–lingual distance (BLD) and interorificial distance (IOD) on axial section of CBCT images.

Statistical analysis

Data were analyzed using the Statistical Package for Social Sciences (SPSS) for Windows software, version 26.0 (SPSS Inc., Chicago, IL, USA). To assess the reliability of assessments, inter-evaluator and intra-evaluator agreement for detecting two canals were estimated using Cohen's kappa based on the analysis of 20 CBCT images. The normality of variables was evaluated using the Kolmogorov-Smirnov test. The regional distribution of mandibular incisors with two canals between the genders, age groups, and the right and left hemiarches was evaluated using the chi-square test (χ^2). The relationship between BLD, IOD and BLD/IOD values and demographics (age, gender, tooth side, and tooth type) was assessed using the Kruskal-Wallis and Mann-Whitney U tests. The correlation between the BLD and the IOD was analyzed using the Pearson correlation coefficient and linear regression model. A significance level was set at $p<0.05$.

A post-hoc power analysis was performed to evaluate whether the total sample size (≈ 336) was adequate to detect the observed association between BLD and IOD. Using the G*Power ver. 3.1 (Heinrich Heine University Düsseldorf, Düsseldorf, Germany) software (Correlation: Bivariate normal model; two-tailed; $\alpha=0.05$), the observed $r=0.392$ with $N=336$ yielded an achieved power >0.99. This indicates the study was sufficiently powered to detect the reported association.

Results

The inter-evaluator ($\kappa=0.84$) and intra-evaluator ($\kappa=0.92$) reliability values indicated good agreement. A total of 1344 mandibular incisors (672 central and 672 lateral) from 336 patients (164 males (49%), 172 females (51%)) were included. The mean age was 40.68 years. Two canals were identified in 25% of the mandibular incisors (336/1344). The prevalence of two canals did not differ significantly according to gender ($\chi^2=2.969$, df=1, $p>0.05$), age group ($\chi^2=1.288$, df=2, $p>0.05$), or tooth side ($\chi^2=0.337$, df=1, $p>0.05$). Vertucci Type I was the most frequent canal configuration overall, whereas Vertucci Types II and III were predominantly observed in mandibular incisors with two canals (Fig. 2).

The mean and standard deviation (SD) values of the BLD, IOD, and BLD/IOD were 6.09±0.77, 1.16±0.36, and 5.81±2.18, respectively. Table 1 shows the anatomical distance comparisons between age groups, gender, tooth side, and tooth type. Regarding age groups, the Kruskal-Wallis test indicated a significant difference in BLD among age groups ($H=10.146$, df=2, $p<0.05$). Group 3 had significantly lower BLD values compared to Groups 1 and 2 ($p<0.05$). IOD ($H=0.825$, df=2, $p>0.05$) and BLD/IOD ($H=5.561$, df=2, $p>0.05$) values did not differ significantly ($p>0.05$).

On the other hand, both females and males, two different hemiarches, and tooth types had similar BLD (Gender: U=13604.5, Standardized test statistics:-0.736, p>0.05, side: U=14276.0, Standardized test statistics: - 0.005, p>0.05, tooth type: U=15152.5, Standardized test statistics: - 0.067, p>0.05), IOD (Gender: U=13604.5, Standardized test statistics: -0.739, p>0.05, side: U=14277.0, Standardized test statistics: -0.004, p>0.05, tooth type: U=14504.5, Standardized test statistics: -0,007, p>0.05), and BLD/IOD (Gender: U=15585.5, Standardized test statistics: 1.467,p>0.05, side: U=14026.0, Standardized test statistics: -0.283, p>0.05, tooth type: U=13604.5, Standardized test statistics: -0.283, p>0.05) values.

Table 2 demonstrates the mean and SD values of BLD ($H=11.519$, df=6, $p>0.05$), IOD ($H=8.704$, df=6,

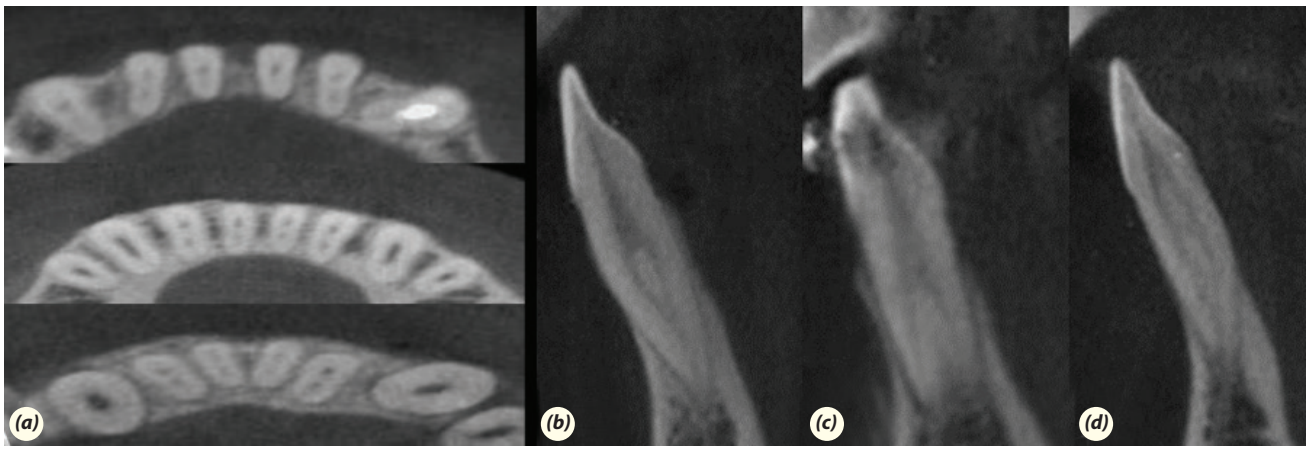

Fig. 2. Axial CBCT views of mandibular incisors with two canals **(a)**. Sagittal CBCT views of mandibular incisors with root canal morphology of Vertucci type III **(b)**, type V **(c)**, and type VI **(d)**.

Table 1. The mean, standard deviation, and p values of the amount of removed dentin thickness in experimental groups (%)

Age	n	BLD (mm)	IOD (mm)	BLD/IOD
Group 1 (17-35 years)	124	6.16±0.80a	1.16±0.35	5.82±2.02
Group 2 (36-55 years)	154	6.15±0.75a	1.15±0.40	6.03±2.46
Group 3 (>55 years)	58	5.77±0.69b	1.19±0.32	5.24±1.63
p-value		0.006	0.662	0.062
Gender				
Female	164	6.07±0.83	1.17±0.36	5.71±2.12
Male	172	6.11±0.71	1.15±0.38	5.92±2.25
p-value		0.340	0.460	0.142
Side				
Right	168	6.09±0.75	1.16±0.38	5.85±2.28
Left	168	6.06±0.80	1.14±0.36	5.88±2.10
p-value		0.996	0.997	0.777
Tooth type				
Central	168	6.19±0.32	1.18±0.23	5.95±2.13
Lateral	168	5.93±0.52	1.08±0.12	5.49±2.20
p-value		0.640	0.597	0.677

Different lowercase letters in the same column indicate statistically significant differences between groups (p<0.05).

p<0.05), and BLD/IOD (H=10.051, df=6, p<0.05) according to the Vertucci classification and apical termination. Accordingly, Vertucci types did not affect the anatomical distance values significantly (p>0.05). In addition, Type A apical termination had significantly higher BLD/IOD values than Type B (U=7122.0, Standardized test statistics: -1.958, p<0.05). Furthermore, a significant positive correlation was found between BLD and IOD (correlation coefficient = 0.392, p<0.05, R2: 0.154).

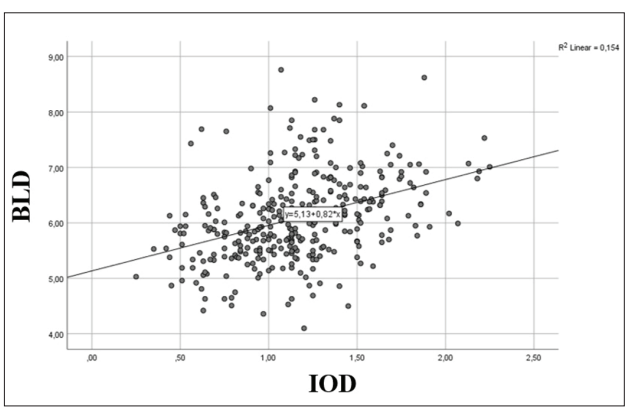

Fig. 3. Pearson correlation between BLD and IOD values.

Discussion

Understanding anatomical variations is crucial for suc-

Table 2. Mean and standard deviations of buccal–lingual distance (BLD), interorificial distance (IOD), and BLD/IOD ratio by Vertucci classification and apical termination.

Vertucci Classification	n	BLD (mm)	IOD (mm)	BLD/IOD
Type I	1008			
Type II	47	5.88±0.75	1.09±0.38	6.11±2.51
Type III	235	6.18±0.80	1.16±0.37	5.90±2.24
Type IV	36	5.94±0.53	1.23±0.33	5.14±1.34
Type V	13	6.01±0.83	1.19±0.28	5.36±1.54
Type VI	1	5.61	0.51	11.00
Type VII	4	5.46±0.17	1.01±0.10	5.42±0.40
p-value		0.074	0.191	0.123
Apical Termination				
Type A	282	6.12±0.80	1.15±0.38	5.94±2.30a
Type B	54	5.96±0.62	1.22±0.33	5.26±1.52b
p-value		0.134	0.196	0.047

Different lowercase letters in the same column indicate statistically significant differences between groups ($p<0.05$).

cessful endodontic treatment, as undetected canals can compromise disinfection, promote persistent periapical pathology, and adversely affect prognosis. In this sense, this study provides comprehensive insights into the root canal morphology of mandibular incisors, particularly the relationship between canal configurations, BLD, and IOD values, as visualized using CBCT.

The prevalence of two canals in mandibular incisors has been recently reported in a global meta-analysis as 21.9% for mandibular central incisors and 26.0% for lateral incisors (26). Similarly, a recent meta-analysis conducted in the Turkish population reported a 34% prevalence of lingual canals in mandibular incisors (27). The findings of the present study revealed a 25% prevalence of lingual canals, which is compatible with the rates reported by Al-Qudah and Awawdeh (26.2%) and Han (21.5%) (18,28). In this study, Vertucci Types III and II were predominantly observed in teeth with two canals, which is consistent with CBCT and micro-CT studies reporting similar configuration patterns in mandibular incisors (21,29). Variations in methods for examining root canal morphology (e.g., radiographic examination, sectioning, staining, and clearing), study design (in vivo and ex vivo), sample sizes, and ethnic backgrounds may account for the differences in the reported prevalence of two canals in mandibular incisors (1,8). This consistency reinforces the importance of clinicians considering anatomical variations, particularly in populations with a higher prevalence of two canals. In this sense, the results of the study also reflect the complexity of root canal systems in mandibular incisors with two canals and highlight the necessity for advanced imaging techniques to detect and classify variations accurately.

A novel aspect of this study was the classification of apical termination in mandibular incisors with two canals as a single apical foramen (Type A) and separate apical foramina (Type B). Teeth with Type A terminations exhibited significantly higher BLD/IOD ratios compared to Type B, suggesting that merging canals tend to maintain shorter distances throughout the coronal and middle thirds before convergence. This finding has important clinical implications, as the apical termination type may influence cleaning, shaping, and obturation strategies. Furthermore, the positive correlation observed between BLD and IOD further emphasizes the interconnectedness of anatomical parameters in mandibular incisors. These findings indicate that the distance between canal orifices can provide useful information when evaluating canal morphology. However, only 15% of the variance is explained, and therefore, the predictive value is limited. Accordingly, the BLD–IOD relationship should be considered as supportive information rather than serving as a predictive parameter.

The lack of significant differences in canal prevalence by gender, age, or tooth side suggests that the occurrence of two canals is a general anatomical trait, independent of demographic factors (30). In this sense, different results were reported in the literature. While some studies found no difference between genders (31,32), some others declared males showed higher odds of having a second root canal (33,34). Moreover, in the case of age, a recent systematic review meta-analysis reported that age does not influence the second root canal prevalence (34). However, an important aspect of the age-related decrease in BLD indicates the impact of secondary dentin deposition on canal morphology over time (35). This progressive reduction in

canal dimensions may mask the presence of secondary canals, increasing the diagnostic challenge in older patients.

Although the present analysis revealed no statistically significant differences in anatomical distance parameters across Vertucci canal configurations, this finding should be interpreted within the context of the study design, particularly in light of the unequal distribution of canal configuration subtypes. The very small sample sizes observed for rare configurations, such as Vertucci Type VI and Type VII, limit the statistical power to detect differences and restrict the extent to which meaningful comparative inferences can be drawn. Consequently, results related to these rare configurations should be regarded as descriptive and interpreted with caution rather than as evidence of true anatomical equivalence across all Vertucci types.

The study also underscores the utility of CBCT in diagnosing complex canal configurations. By providing detailed three-dimensional images, CBCT enables clinicians to identify secondary canals that might otherwise go undetected with traditional two-dimensional radiographs (14). This capability is particularly valuable in mandibular incisors, where the small size and narrow orifices can obscure secondary canals, leading to incomplete treatment (36).

While this study provides valuable insights, certain limitations should be acknowledged. A potential limitation could have arisen from variations in tooth size among individuals. Since larger teeth tend to have proportionally greater IOD, directly comparing IOD values across different teeth could introduce bias. To address this, the ratio of IOD to the BLD for each tooth was calculated in this study, allowing for normalization and enabling more accurate comparisons independent of tooth size. However, no study classified the apical terminus in mandibular incisors as was performed in this study. Thus, results should be interpreted with caution. Additionally, differences in CBCT parameters such as FOV and voxel size can influence image resolution, and this limitation may affect the accurate assessment of apical terminations, which are difficult to capture fully with imaging-based evaluation. Furthermore, determining the level at which both canals become simultaneously visible may involve a degree of observer-related subjectivity. Moreover, the retrospective nature of the study and the reliance on CBCT records may introduce selection bias. Finally, although the study includes a large sample size, the patients were primarily selected from a single institution, limiting the generalizability of the findings across different populations.

Conclusion

This study underscores the complexity of mandibular incisor canal morphology, providing actionable insights for improving diagnosis and treatment. The significant correlation between BLD and IOD may provide supportive information when evaluating canal morphology, while the differences in apical termination types highlight the need for tailored clinical approaches. CBCT imaging has proven invaluable in detecting and analyzing these variations, reinforcing its role as a critical diagnostic tool in modern endodontics. Future research should explore the implications of these findings in clinical practice, particularly in developing more effective protocols for managing mandibular incisors with two canals.

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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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The Path Toward Preserving the Tooth Between Knowledge and Fear: Patient Perceptions of Root Canal Treatment

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Purpose: To assess patients' knowledge, awareness, experiences, and attitudes toward root canal treatment (RCT) and to explore how education level and prior treatment experience are associated with treatment preferences.

Methods: A descriptive cross-sectional survey was administered to 689 adults presenting to Uşak University Faculty of Dentistry. The two-section questionnaire captured demographics and 16 items on sources of information, past experiences, fear, awareness, and preferences. Data were analysed using descriptive statistics, the Pearson chi-square test or Fisher's exact test, and binary logistic regression (α=0.05).

Results: A total of 689 participants were included in the study. Of these, 79.7% reported having previously undergone RCT, and 88.2% of those individuals evaluated their treatment experience positively. Overall, 79.7% perceived RCT as a successful treatment modality, and 78.2% reported that they would prefer RCT over extraction or implant placement for an infected tooth. Pain related concerns were identified as the most common source of fear by 46.2% of participants. Educational level was significantly associated with self-reported knowledge regarding RCT ($p<0.001$), and higher knowledge levels were associated with perceiving RCT as successful ($p=0.002$) and preferring RCT as a treatment option ($p<0.001$). However, in multivariable analysis, treatment preference was associated primarily with the perception that RCT weakens the tooth rather than with knowledge level itself ($p<0.001$). The vast majority of participants (96.2%) indicated that the public should be more thoroughly informed about RCT.

Conclusion: This study demonstrates that patients' attitudes and treatment preferences regarding root canal treatment are shaped by perceptions and expectations rather than by knowledge level alone. Expectations related to pain and assumptions about tooth durability play a notable role in the decision-making process. In particular, the widespread belief that root canal treatment weakens the tooth may negatively influence patients' attitudes toward conservative treatment options. These findings indicate that patient education should extend beyond the provision of factual information and be supported by patient centered and evidence-based communication strategies that address misconceptions and expectations. Clear and accessible public information may help promote appropriate treatment choices.

Keywords: Root canal treatment; knowledge; dental anxiety; survey.

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Introduction

Endodontic treatment involves the management of pulpal and apical disease through chemo-mechanical cleaning and obturation of the root canal system, followed by adequate coronal sealing with biocompatible materials, with the overarching goal of preserving the natural tooth whenever possible (1). Contemporary evidence from systematic reviews indicates that endodontically treated posterior teeth demonstrate high survival rates in the medium and long term, although prognosis may vary according to tooth-related and restoration-related factors (2).

Despite the efficacy and widespread application of root canal treatment, many patients still perceive it as a painful and anxiety-inducing procedure (3,4). The literature indicates that this fear often stems from previous painful dental experiences, misinformation acquired from social circles or social media, and inadequate knowledge regarding the treatment process (5,6). The erroneous belief that antibiotic therapy alone can cure infected teeth may also lead patients to avoid treatment and opt for unnecessary tooth extractions (7). Contemporary evidence from longitudinal clinical studies further indicates that outcomes of primary root canal therapy remain favourable in modern practice (8).

Recent studies conducted in various populations have demonstrated that patients' levels of knowledge, awareness, and attitudes towards root canal treatment are influenced by demographic factors such as age, gender, and educational attainment (9,10). It has been reported that individuals with higher levels of education possess greater awareness of endodontic treatment and exhibit more positive attitudes towards it; conversely, individuals with limited knowledge and negative past experiences tend to exhibit increased dental anxiety, a tendency to postpone treatment, and lower compliance rates (11,12).

Understanding the public's level of knowledge about root canal treatment and the factors influencing their decision to undergo this procedure is important for improving dentist–patient communication, reducing dental anxiety, and promoting preventive oral health behaviors. (13,14). However, there is a lack of comprehensive data in Türkiye that simultaneously evaluates how patients' educational backgrounds, previous dental experiences, and beliefs influence their treatment preferences.

Accordingly, the aim of this study is to assess patients' levels of knowledge, awareness, and attitudes towards root canal treatment and to identify the primary factors influencing their preferences for endodontic therapy. The study hypothesizes that higher educational attainment is associated with a greater preference for endodontic treatment in cases requiring such intervention.

Materials and Methods

This study was conducted in accordance with the principles of the Declaration of Helsinki and was approved by the Non-Interventional Clinical Research Ethics Committee of the Faculty of Dentistry at Uşak University (Decision No: 2025/580, Date: 06.03.2025). The research was carried out within the Faculty of Dentistry at Uşak University between March 2025 and August 2025.

This investigation is a descriptive and cross-sectional survey study aimed at evaluating patients' levels of knowledge, awareness, and attitudes towards root canal treatment. Individuals aged between 18 and 80 years who presented to the faculty for examination or treatment in any dental specialty, possessed adequate cognitive communication skills, and voluntarily agreed to participate were included in the study. Participants who declined to complete the questionnaire, were under the age of 18, or submitted incomplete responses were excluded. A total of 689 participants were included in the study.

As the data collection instrument, a structured questionnaire form (Figure 1) was developed based on a comprehensive literature review (2–4). Survey questions were asked in Turkish. The questionnaire was constructed using validated scales from previous studies and its content validity was ensured through consultation with two endodontic specialists.

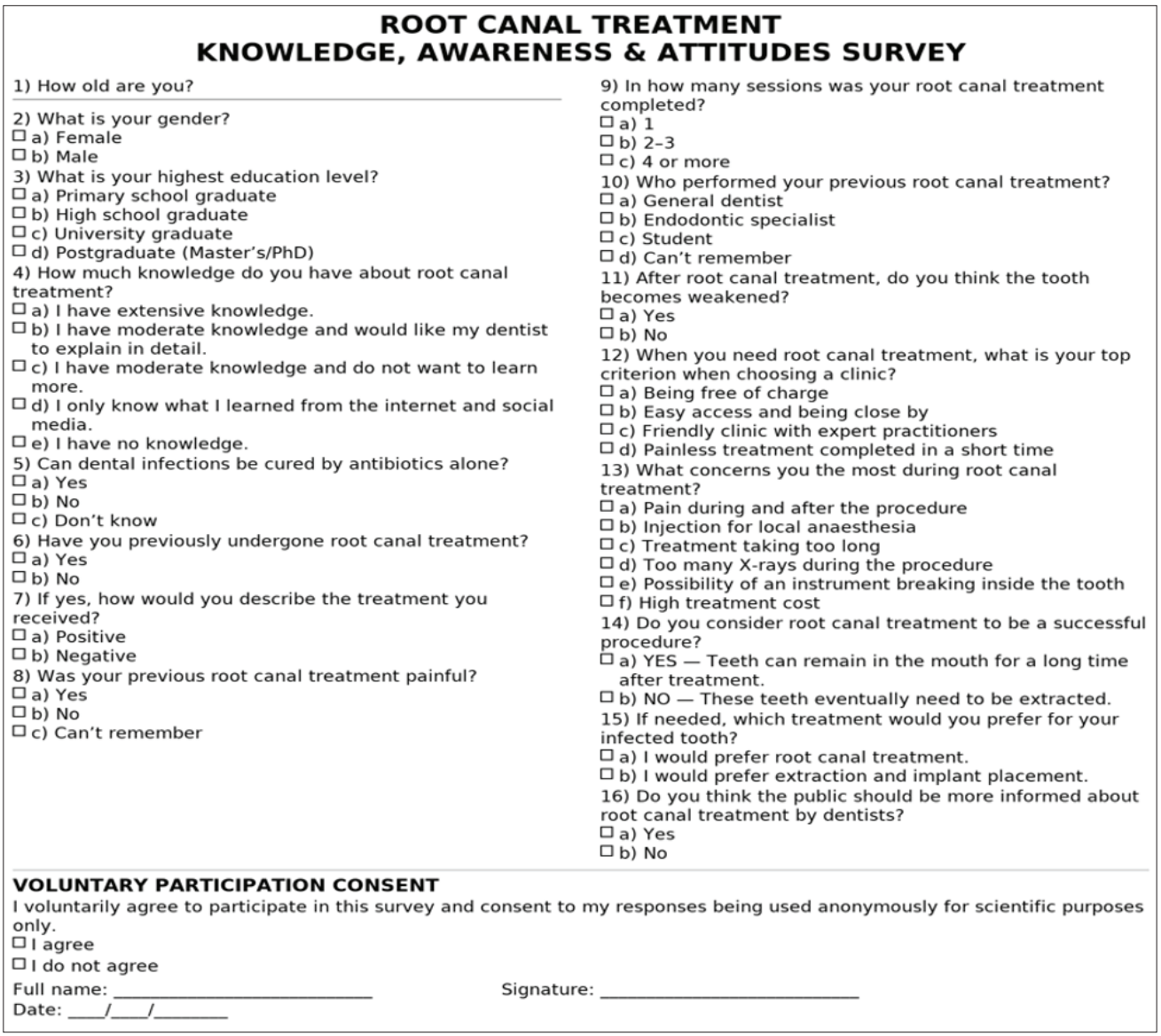
The questionnaire comprises two sections:

- The first section includes demographic information such as age, gender, and educational level.
- The second section consists of 16 questions evaluating patients' sources of information regarding root canal treatment, previous experiences, levels of fear, awareness, and treatment preferences (Figure 1).

The questionnaires were administered to patients who presented to the Faculty of Dentistry at Uşak University for examination or treatment in any dental specialty. The data collection process was conducted through face-to-face interviews, during which the purpose and scope of the study were clearly explained to the participants. Participation was entirely voluntary, and no personal information (such as name, telephone number, or patient registration number) was recorded. Participants were informed of their right to withdraw from the study at any time.

Validity and Reliability of the Questionnaire

The questionnaire was developed based on a comprehensive review of previously published questionnaire-based studies evaluating patients' knowledge, awareness, anxiety, and attitudes toward root canal treatment (3,4,7,13,15). Content validity was ensured through independent evalu-



ROOT CANAL TREATMENT
KNOWLEDGE, AWARENESS & ATTITUDES SURVEY

1) How old are you?

2) What is your gender?
☐ a) Female
☐ b) Male

3) What is your highest education level?
☐ a) Primary school graduate
☐ b) High school graduate
☐ c) University graduate
☐ d) Postgraduate (Master's/PhD)

4) How much knowledge do you have about root canal treatment?
☐ a) I have extensive knowledge.
☐ b) I have moderate knowledge and would like my dentist to explain in detail.
☐ c) I have moderate knowledge and do not want to learn more.
☐ d) I only know what I learned from the internet and social media.
☐ e) I have no knowledge.

5) Can dental infections be cured by antibiotics alone?
☐ a) Yes
☐ b) No
☐ c) Don't know

6) Have you previously undergone root canal treatment?
☐ a) Yes
☐ b) No

7) If yes, how would you describe the treatment you received?
☐ a) Positive
☐ b) Negative

8) Was your previous root canal treatment painful?
☐ a) Yes
☐ b) No
☐ c) Can't remember

9) In how many sessions was your root canal treatment completed?
☐ a) 1
☐ b) 2–3
☐ c) 4 or more

10) Who performed your previous root canal treatment?
☐ a) General dentist
☐ b) Endodontic specialist
☐ c) Student
☐ d) Can't remember

11) After root canal treatment, do you think the tooth becomes weakened?
☐ a) Yes
☐ b) No

12) When you need root canal treatment, what is your top criterion when choosing a clinic?
☐ a) Being free of charge
☐ b) Easy access and being close by
☐ c) Friendly clinic with expert practitioners
☐ d) Painless treatment completed in a short time

13) What concerns you the most during root canal treatment?
☐ a) Pain during and after the procedure
☐ b) Injection for local anaesthesia
☐ c) Treatment taking too long
☐ d) Too many X-rays during the procedure
☐ e) Possibility of an instrument breaking inside the tooth
☐ f) High treatment cost

14) Do you consider root canal treatment to be a successful procedure?
☐ a) YES — Teeth can remain in the mouth for a long time after treatment.
☐ b) NO — These teeth eventually need to be extracted.

15) If needed, which treatment would you prefer for your infected tooth?
☐ a) I would prefer root canal treatment.
☐ b) I would prefer extraction and implant placement.

16) Do you think the public should be more informed about root canal treatment by dentists?
☐ a) Yes
☐ b) No

VOLUNTARY PARTICIPATION CONSENT

I voluntarily agree to participate in this survey and consent to my responses being used anonymously for scientific purposes only.
☐ I agree
☐ I do not agree

Full name: _____ Signature: _____
Date: ____/____/_____

Fig. 1. Patient survey instrument used to assess knowledge, awareness, experiences, and attitudes toward root canal treatment.

ation by two experienced endodontists, who assessed each item in terms of clarity, relevance, and its ability to adequately represent the intended constructs. Minor linguistic revisions were made in accordance with their recommendations.

External reliability (test–retest reliability) was assessed by re-administering the questionnaire to a subset of 30 participants from the study population after a one-week interval. Intraclass correlation coefficients (ICCs) and corresponding 95% confidence intervals were calculated for all items, demonstrating a high level of agreement across the questionnaire (ICC>0.90).

Internal consistency was evaluated using Cronbach's alpha coefficient, which yielded a value of 0.756, indicating acceptable internal reliability of the questionnaire for use in similar populations.

Statistical Analysis

Data were analysed using IBM SPSS Statistics version 27.0. Descriptive statistics were presented as frequency, percentage, mean ± standard deviation, and median (interquartile range), as appropriate. Associations between categorical variables were assessed using the Pearson Chi-Square test or Fisher's Exact test when expected cell counts were insufficient. The distribution of age across knowledge categories was evaluated using the Kruskal–Wallis test due to non-normal distribution.

Table 1. Distribution of participants according to demographic characteristics and responses to the questionnaire on root canal treatment (n=689)

	n	%
Gender		
Female	463	67.2
Male	226	32.8
Educational Level		
Primary School Graduate	62	9.0
Secondary School Graduate	207	30.0
University Graduate	362	52.5
Postgraduate Degree Holder	58	8.4
How much knowledge do you have about root canal treatment?		
Extensive knowledge	73	10.6
Moderate knowledge, not interested in learning more	174	25.3
Moderate knowledge, interested in learning more	267	38.8
Knowledge acquired only from internet and social media	98	14.2
No knowledge	76	11.0
Can a dental infection be cured solely with antibiotic use?		
Yes	171	24.9
No	339	49.4
Do not know	176	25.7
Have you previously undergone root canal treatment?		
Yes	549	79.7
No	140	20.3
If yes, how would you describe the treatment received?		
Positive	484	88.2
Negative	65	11.8
Was the previous root canal treatment painful?		
Yes	216	39.5
No	266	48.6
Cannot recall	65	11.9
How many sessions did your root canal treatment require?		
One session	125	23.0
Two to three sessions	353	64.9
Four or more sessions	66	12.1
Who performed your previous root canal treatment?		
General Dentist	417	76.2
Endodontic Specialist	91	16.6
Dental Student	39	7.1
Do you believe the tooth becomes weakened after root canal treatment?		
Yes	347	50.5
No	340	49.5
When requiring root canal treatment, what is your primary criterion for choosing a clinic?		
Ease of access and proximity	35	5.1
Painless and rapid treatment	275	39.9
Friendly and expert clinicians	339	49.2
Free of charge	40	5.8
What concerns you most during root canal treatment?		
Pain during and after the procedure	317	46.2
Administration of anaesthesia via injection	90	13.1
Prolonged duration of treatment	144	21.0
Excessive radiographic imaging during treatment	13	1.9

Possibility of instrument fracture within the tooth	73	10.6
High cost of treatment	46	6.7
Other	3	0.4
Do you consider root canal treatment to be a successful procedure?		
YES – Teeth can remain in the mouth for a long time after treatment	549	79.7
NO – These teeth eventually require extraction	140	20.3
Which treatment would you prefer for an infected tooth?		
I would prefer root canal treatment	539	78.2
I would prefer extraction and implant placement	150	21.8
Do you believe the public should be more informed about root canal treatment by dental professionals?		
Yes	661	96.2
No	26	3.8
Age		
	Minimum–Maximum	Mean ± SD (Median)
	18–80	42.28±14.45 (42)

To identify factors independently associated with treatment preference, a binary logistic regression analysis was performed using a forward conditional method. Preference for root canal treatment versus extraction and implant placement was defined as the binary dependent variable. Categorical variables were dummy coded and appropriate reference categories were selected. Odds ratios with 95% confidence intervals were reported. Model fit was assessed using the Hosmer–Lemeshow goodness-of-fit test, and model explanatory power was evaluated using Nagelkerke R^2. A p-value of less than 0.05 was considered statistically significant.

Results

A total of 689 participants were included in the study. The participants' ages ranged from 18 to 80 years, with a mean age of 42.28±14.45 (median=42). Of the participants, 67.2% were female and 32.8% were male. Regarding educational attainment, 9.0% had completed primary education, 30.0% secondary education, 52.5% held a university degree, and 8.4% had completed postgraduate studies. The demographic characteristics of the participants and the distribution of their responses are presented in Table 1.

When evaluating responses to the question "How much knowledge do you have about root canal treatment?", 10.6% of participants reported having extensive knowledge, 38.8% stated they had moderate knowledge and wished to learn more, 25.3% had moderate knowledge but did not wish to learn more, 14.2% had acquired knowledge solely from internet and social media sources, and 11.0% indicated having no knowledge at all. In response to the question "Can a dental infection be cured solely with antibiotic use?", 49.4% answered "no", 24.9% "yes", and 25.7% "do not know". Furthermore, 79.7% of participants reported having previously undergone root canal treatment, while 20.3% had not. Among those who had received treatment, 88.2% evaluated the procedure positively, whereas 11.8% described it as negative.

The proportion of participants who characterised root canal treatment as painful was 39.5%, while 48.6% considered it painless. The treatment was completed in two or three sessions in 64.9% of cases, in a single session in 23%, and in four or more sessions in 12.1%. The procedures were performed by general dentists in 76.2% of cases, by endodontic specialists in 16.6%, and by dental students in 7.1%. Half of the participants (50.5%) believed that the tooth becomes weakened following root canal treatment, while the remaining 49.5% disagreed with this view.

The most commonly feared aspect of root canal treatment was "pain during and after the procedure" (46.2%). Additionally, 21% of participants expressed concern about the duration of the treatment, 13.1% about the administration of anaesthesia, 10.6% about the possibility of instrument fracture, and 6.7% about the cost of treatment. Regarding clinical preferences, 49.2% prioritised clinics with friendly and expert practitioners, 39.9% preferred painless and swiftly completed treatments, 5.8% favoured free services, and 5.1% cited ease of access as their primary consideration.

A total of 79.7% of participants considered root canal treatment to be a successful procedure, whereas 20.3% believed that the tooth would ultimately require extraction. When asked about their preferred treatment for an infected tooth, 78.2% chose root canal therapy, while 21.8% opted for extraction and implant placement. Moreover, 96.2% of participants stated that the public should be more thoroughly informed about root canal treatment by dental professionals.

Table 2. Distribution of demographic and behavioral variables according to participants' knowledge levels about root canal treatment and their statistical relationships (n=689)

	Extensive Knowledge		Moderate, Knowledge Not Interested		Moderate Knowledge Interested		Knowledge from Internet/ Social Media		No Knowledge			
	n	%	n	%	n	%	n	%	n	%	Test Statistic	p
Gender												
Female	42	9.1	116	25.1	184	39.7	64	13.8	57	12.3	5.735	0.220
Male	31	13.8	58	25.8	83	36.9	34	15.1	19	8.4		
Educational Level												
Primary School	1a	1.6	14[a]	22.6	12[a]	19.4	8[a]	12.9	27[b]	43.5	89.852	<0.001*
High School	16[a]	7.7	56[a]	27.1	79[a]	38.2	34[a]	16.4	22[a]	10.6		
University	46[a]	12.7	90[a]	24.9	149[a]	41.3	53[a]	14.7	23[b]	6.4		
Postgraduate	10[a]	17.2	14[a]	24.1	27[a]	46.6	3[a]	5.2	4[a]	6.9		
Can a dental infection be cured solely with antibiotic use?												
Yes	24[a]	14.0	44[a]	25.7	63[a]	36.8	23[a]	13.5	17[a]	9.9	38.351	<0.001*
No	45[a]	13.3	90[ab]	26.5	137[ab]	40.4	41[ab]	12.1	26[b]	7.7		
Do not know	2[a]	1.1	39[b]	22.3	67[b]	38.3	34[bc]	19.4	33[c]	18.9		
Do you consider root canal treatment a successful procedure?												
Yes – Teeth remain after treatment	62[a]	11.3	144[a]	26.3	221[a]	40.3	72[ab]	13.1	49[b]	8.9	17.008	0.002*
No – Teeth eventually require extraction	11[a]	7.9	30[a]	21.4	46[a]	32.9	26[ab]	18.6	27[b]	19.3		
Preferred treatment for an infected tooth												
Prefer root canal treatment	63[a]	11.7	140[a]	26.0	219[a]	40.7	71[ab]	13.2	45[b]	8.4	23.596	<0.001*
Prefer extraction and implant	10[a]	6.7	34[a]	22.7	48[a]	32.0	27[ab]	18.0	31[b]	20.7		
What concerns you most during root canal treatment?												
Experiencing pain during and after the procedure	26	8.2	81	25.6	131	41.3	52	16.4	27	8.5	28.302**	0.180
Administration of anaesthesia via injection	9	10.0	28	31.1	25	27.8	12	13.3	16	17.8		
Prolonged duration of the treatment	18	12.6	36	25.2	59	41.3	15	10.5	15	10.5		
Excessive radiographic imaging during the procedure	1	7.7	2	15.4	5	38.5	2	15.4	3	23.1		
Possibility of instrument fracture within the tooth	13	17.8	15	20.5	27	37.0	9	12.3	9	12.3		
High cost of treatment	6	13.0	8	17.4	20	43.5	7	15.2	5	10.9		
Other	0	0.0	2	66.7	0	0.0	0	0.0	1	33.3		

*p<0.05, **Fisher's Exact test. %: Row percentage. Different superscript letters indicate statistically significant differences between column proportions within the same row (p<0.05).

Table 3. Distribution of variables related to previous root canal treatment experience according to participants' perception of treatment success and their statistical relationships (n=689)

	Yes – Teeth remain in the mouth after treatment		No – These teeth eventually require extraction		Test Statistic	p
	n	%	n	%		
Have you previously undergone root canal treatment?						
Yes	460[a]	83.8	89[b]	16.2	28.162	<0.001*
No	89[a]	63.6	51[b]	36.4		
If yes, how would you describe the treatment received?						
Positive	421[a]	87.0	63[b]	13.0	30.717	<0.001*
Negative	39[a]	60.0	26[b]	40.0		
How many sessions did your root canal treatment require?						
1	103	82.4	22	17.6	0.390	0.823
2-3	299	84.7	54	15.3		
4 or more	55	83.3	11	16.7		
Who performed your previous root canal treatment?						
General Dentist	348	83.5	69	16.5	2.518	0.284
Endodontic Specialist	80	87.9	11	12.1		
Dental Student	30	76.9	9	23.1		

*p<0.05. %: Row percentage. Different superscript letters indicate statistically significant differences between column proportions within the same row (p<0.05).

Table 4. Association between participants' belief that root canal treatment weakens the tooth and their preferred treatment option for an infected tooth (n=689)

	Yes		No		Test Statistic	p
	n	%	n	%		
If necessary, which treatment would you prefer for your infected tooth?						
I would prefer to undergo root canal treatment.	221[a]	41.2	316[b]	58.8	86.104	<0.001*
I would prefer to have the tooth extracted and replaced with an implant.	126[a]	84.0	24[b]	16.0		

*p<0.05. %: Row percentage. Different superscript letters indicate statistically significant differences between column proportions within the same row (p<0.05).

Knowledge level was not significantly associated with age or gender (p>0.05), whereas educational level showed a significant association with knowledge, with higher knowledge levels observed among participants with university and postgraduate education (p<0.001) (Table 2).

Analysis of the relationship between knowledge level and treatment approach revealed that individuals with higher levels of knowledge were more likely to regard root canal treatment as successful (p=0.002) and to prefer it over implant placement when necessary (p<0.001). Additionally, those with greater knowledge more frequently agreed with the statement that "a dental infection cannot be cured solely with antibiotic use" (p<0.001). These findings are summarised in Table 2.

When examining the relationship between prior experience with root canal treatment and attitudes towards the procedure, it was found that individuals who had previously undergone treatment were more likely to consider it successful (p<0.001). Similarly, among participants who described their past treatment experience as positive, the vast majority 87.0% viewed root canal therapy as an effective method (p<0.001), whereas this proportion dropped to 70.8% among those who evaluated the treatment negatively (Table 3).

No statistically significant associations were observed between the number of treatment sessions and pain-related experiences, fear variables, or perceived treatment success (p>0.05). Similarly, the practitioner performing the treatment was not associated with these outcomes.

A statistically significant relationship was identified between responses to the question "Do you believe the tooth becomes weakened after root canal treatment?" and "Which treatment would you prefer for an infected tooth?" (p<0.001). Among participants who believed that

Table 5. Association between number of root canal treatment sessions and patients' experiences, fears, and perceptions

Number of root canal treatment sessions	1 session		2–3 sessions		4 or more sessions		Test statistic	p
	n	%	n	%	n	%		
Was the previous root canal treatment painful?								
Yes	48	22.2	136	63.0	32	14.8	8.719	0.069
No	60	22.6	184	69.2	22	8.3		
Cannot recall	16	26.7	33	55.0	11	18.3		
What concerns you most during root canal treatment?								
Pain during and after the procedure	56	21.8	170	66.1	31	12.1	8.171**	0.760
Administration of anaesthesia via injection	23	30.3	45	59.2	8	10.5		
Prolonged duration of treatment	20	18.9	69	65.1	17	16.0		
Excessive radiographic imaging during treatment	1	11.1	6	66.7	2	22.2		
Possibility of instrument fracture within the tooth	14	26.9	33	63.5	5	9.6		
High cost of treatment	11	26.8	27	65.9	3	7.3		
Other	0	0.0	2	100.0	0	0.0	0.390	0.823
Do you consider root canal treatment to be a successful procedure?								
YES – Teeth can remain in the mouth for a long time after treatment	103	22.5		299	65.4	55	12.0	
NO – These teeth eventually require extraction	22	25.3	54	62.1	11	12.6		

*p<0.05. %: Row percentage. Pearson Chi-square test or Fisher's Exact test was used as appropriate.

Table 6. Binary logistic regression analysis of factors associated with preference for root canal treatment in an infected tooth

Variables	β	S.E.	Wald	p	O.R.	95% CI Lower	95% CI Upper
Gender (Male)	1.395	0.600	5.402	0.020	4.034	1.244	13.075
Do you believe the tooth becomes weakened after root canal treatment? (No)	1.666	0.530	9.867	0.002	5.290	1.871	14.956
Do you consider root canal treatment to be a successful procedure? (Yes)	6.003	0.561	114.483	<0.001*	404.450	134.692	1214.476
Constant	-3.499	0.565	38.324	<0.001*	0.030		
Hosmer–Lemeshow test: χ^2=1.643, p=0.801							
Cox & Snell R^2=0.463; Nagelkerke R^2=0.768							
Overall correct classification rate=95.6%							

* p<0.05. S.E.: Standard error; OR: Odds ratio; CI: Confidence interval.

the tooth becomes weakened after root canal treatment, implant therapy was preferred by 84.0% of those selecting implants, whereas only 16.0% of implant-preferring participants did not hold this belief (Table 4).

Educational level was not significantly associated with responses to the questions regarding antibiotic-only treatment of dental infections or the need for public information about root canal treatment (p>0.05).

Additional analyses examined the relationship between the number of sessions required for root canal treatment and participants' previous painful experiences, pain-related fears, and perception of treatment success. No statistically significant associations were found between the number of treatment sessions and whether the previous treatment was painful (p=0.069), the most feared aspect of root canal treatment (p=0.760), or the belief that root canal treatment is a successful procedure (p>0.05) (Table 5).

To identify factors independently associated with treatment preference, a binary logistic regression analysis was performed. In the final model, male gender, the belief that root canal treatment is a successful therapeutic option, and the perception that root canal treatment weakens the tooth were found to be significantly associated with treatment preference (p<0.05). The model demonstrated good fit according to the Hosmer–Lemeshow test (p=0.801) and showed high explanatory power (Nagelkerke R^2=0.768) (Table 6).

Discussion

The hypothesis of the present study was that a higher level of education would increase the likelihood of preferring root canal treatment. The findings demonstrated that educational attainment was significantly associated with greater knowledge regarding root canal treatment and with more positive attitudes toward this therapy. However, multivariable analyses revealed that treatment preference was determined primarily by perception based factors rather than by educational level or knowledge itself. This finding indicates that the hypothesis was supported indirectly rather than directly.

Previous studies have similarly reported that individuals with higher educational attainment tend to exhibit greater awareness and higher self reported knowledge regarding root canal treatment (3,10,16-18). Nevertheless, patient centred survey studies emphasize that increased awareness does not necessarily result in more consistent or evidence based treatment preferences (4,15). Bansal and Jain reported that although many patients were familiar with root canal treatment, their treatment decisions were largely influenced by subjective perceptions related to pain expectations, fear, and anticipated treatment outcomes. Likewise, Manasa et al. (15) demonstrated that despite differences in education and awareness levels, treatment preferences were predominantly shaped by personal beliefs and misconceptions. In line with this literature, the present study shows that although educational level is associated with knowledge, it does not independently predict treatment preference, highlighting the dominant role of perception based factors in endodontic decision making.

The most common source of fear related to root canal treatment was the expectation of experiencing pain during or after the procedure (46.2%), a proportion consistent with values reported in the literature (12,19,20). However, the findings indicate that this fear is not always based on actual painful treatment experiences. Indeed, no statistically significant association was found between previous painful experiences and fear-related variables or perceived treatment success. This suggests that the anxiety observed among patients may be more closely associated with anticipatory or perception-based expectations of pain rather than with real treatment experiences. Consistent with this interpretation, previous research has demonstrated that actual pain levels reported after root canal treatment are generally lower than patients' pre-treatment expectations (21). Previous studies have highlighted that dentist–patient communication plays a central role in shaping these perceptions, and that treatment-related anxiety tends to be lower when clear information is provided regarding the treatment process and pain management strategies (18,22). Therefore, establishing a secure clinical environment supported by transparent information and a trust-based communication approach may play a critical role in reducing perception-driven fears related to endodontic treatment.

The findings indicate that decision making regarding endodontic treatment is driven more by patients' perceptions and expectations of the therapy than by their level of knowledge alone. Accordingly, strategies aimed at shaping treatment preferences should extend beyond the mere provision of information and instead adopt a comprehensive, patient-centred approach that seeks to reframe patients' risk perceptions and expectations related to treatment.

A substantial proportion of participants either believed or were uncertain that dental infections could be treated solely with antibiotic use, indicating the persistence of widespread and enduring misconceptions regarding endodontic treatment. Similar findings in the literature suggest that the belief that antibiotics can replace definitive treatment largely stems from insufficient or inaccurate information (3,23). In contemporary settings, unverified information disseminated through social media and online platforms further reinforces these misconceptions and negatively influences patients' treatment decisions (6,13,24). From a clinical perspective, this may lead to delays in definitive dental care and unnecessary reliance on antibiotics, thereby posing a significant risk in terms of antimicrobial resistance (7). Current evidence-based guidelines emphasize that antibiotics should be considered only as an adjunct in cases of pulpal and periapical infections with systemic involvement, and that definitive management should primarily rely on operative treatment approaches (25,26). In this context, providing patients with clear and accurate information regarding the limited role of antibiotics and the central importance of root canal therapy in infection control is critical for reducing unnecessary antibiotic use and enhancing trust in endodontic treatment.

Positive treatment experiences emerged as an important factor shaping patients' attitudes toward root canal therapy. In the present study, the majority of participants who had previously undergone root canal treatment (88.2%) evaluated their experience positively. Individuals with prior treatment experience who reported a positive outcome were significantly more likely to perceive root canal therapy as a successful treatment. These results suggest that patients' confidence in endodontic treatment is strongly influenced by experiential factors, such as comfort during the procedure and perceived functional outcome, rather than by abstract knowledge alone. Similar observations in

the literature indicate that favourable endodontic experiences are associated with lower anxiety levels and more positive attitudes toward future treatments (13,15).

In this study, the finding that half of the participants believed that teeth become weakened after root canal treatment (50.5%) is clinically meaningful and was shown to directly influence treatment preference. Notably, individuals holding the belief that "root canal treatment weakens the tooth" were more likely to prefer implant therapy for an infected tooth, indicating that this perception plays a substantial role in the decision-making process. Similar perceptions have been reported in the literature, where many patients consider root canal–treated teeth to be structurally fragile and therefore regard extraction or implant placement as more definitive solutions (4,15). However, contemporary endodontic and restorative literature emphasizes that the long-term survival of root canal–treated teeth is determined primarily not by the biological effects of the endodontic procedure itself, but by factors such as the amount of remaining coronal tooth structure and the timing, integrity, and quality of the subsequent restoration. Coronal leakage, delayed or inadequate restoration, insufficient cuspal coverage, and inappropriate restorative design have been identified as the principal causes of structural failure, rather than the root canal treatment per se (27,28). Advances in adhesive dentistry and biomimetic restorative approaches have demonstrated that appropriately restored endodontically treated teeth can exhibit high survival rates and remain functionally stable in the oral cavity over the long term (27,29). Accordingly, current clinical evidence supports the concept that restorative intervention constitutes an integral component of endodontic treatment and that preservation of endodontic–restorative integrity plays a decisive role in maintaining biomechanical durability (30).

In this context, the widespread perception that root canal treatment inherently weakens the tooth appears to stem from limited awareness of modern restorative strategies and the principles of endodontic–restorative integration. Addressing this misconception through patient-centred, evidence-based communication is therefore essential, not only to enhance patient confidence in endodontic therapy, but also to prevent unnecessary tooth extraction or preference for implant treatment.

The absence of a statistically significant association between educational level and the opinion that the public should be informed about root canal treatment ($p=0.447$) indicates that the lack of endodontic awareness is not confined to individuals with lower educational attainment, but rather represents a widespread issue across society. The literature similarly reports comparable knowledge deficiencies across different socioeconomic and educational groups, with a substantial proportion of patients lacking sufficient and accurate information about the root canal treatment process (6,23). This finding suggests that misconceptions and hearsay can shape individuals' treatment perceptions independently of educational level, highlighting the pivotal role of general health literacy in this process (16,22). Therefore, oral health education strategies aimed at improving endodontic awareness should not be limited to specific population groups. Instead, they should adopt an inclusive, patient-centred, and sustainable framework that emphasises clear and accessible communication, corrects prevalent misconceptions, and seeks to reshape patients' expectations regarding endodontic treatment.

Nevertheless, several limitations of this study should be acknowledged. Although the questionnaire demonstrated acceptable internal consistency and test–retest reliability, the evaluation of knowledge and awareness relied on self-reported data, which may be influenced by individual perception and response bias. In addition, construct validity was assessed indirectly. While scenario-based questionnaires have been shown to provide a more objective assessment of clinical decision-making in practitioner-focused research, their applicability is limited in patient-centered studies (31), where self-reported measures remain the primary approach for evaluating knowledge, perceptions, and attitudes.

Furthermore, the use of a convenience sampling method based on a clinical population may have introduced selection bias, as individuals seeking dental care may already hold more favorable attitudes toward dental treatments, including root canal therapy, compared to the general population. Therefore, the generalizability of the findings to the broader community should be interpreted with caution. Future studies employing population-based sampling strategies, validated instruments, and patient-appropriate case-based methodologies may help to further strengthen the existing evidence.

Conclusion

Patients' decisions regarding endodontic treatment appear to be associated primarily with perception-related factors, including expectations of pain, beliefs about treatment success, and assumptions regarding tooth durability, rather than with knowledge level alone. Misconceptions such as the belief that teeth become weakened after root canal treatment and reliance on antibiotics were found to be significantly associated with treatment preferences. These findings underscore the need for patient-centred and evidence-based communication approaches aimed at addressing expectations and correcting misconceptions, par-

ticularly in supporting conservative treatment choices and appropriate antibiotic use. However, these findings should be interpreted with caution due to the cross-sectional design of the study, the reliance on self-reported data, and the clinical-based study population.

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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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Fractal Dimension Analysis of Periapical Alveolar Architecture in Endodontically Treated Teeth Before and After Orthodontic Treatment: A Retrospective Split-Mouth Study

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Purpose: To assess periapical trabeculation of endodontically treated mandibular first molars before (T0) and after (T1) orthodontic treatment using fractal dimension (FD) analysis, and the effect of sex on these changes.

Methods: The study included 32 patients (15 males and 17 females, mean age 17.32±1.71 years). The study group consisted of endodontically treated teeth, and their healthy contralateral counterparts served as controls. FD analysis was performed on 40×40 pixel ROIs from panoramic radiographs at T0 and T1. Paired t-tests were used for comparisons between the study group and their contralateral controls, as well as for T0–T1 comparisons. Independent t-tests were used to evaluate sex-related differences ($p<0.05$).

Results: FD values of the study group were significantly lower than controls at T0 and T1 ($p<0.001$), with a greater T0–T1 increase in the study group. At T0, female FD values were significantly lower than males in the study group ($p=0.014$), but this difference was not significant at T1 ($p>0.05$). Significant T0–T1 FD increases were observed in both sexes and groups ($p<0.05$).

Conclusion: Periapical trabeculation during the healing of endodontically treated teeth was not adversely affected by orthodontic treatment, and sex-related differences tend to balance over time.

Keywords: Endodontically treated teeth; alveolar bone; periapical healing; orthodontic treatment; fractal dimension analysis.

Introduction

The absence of pulp after endodontic treatment may affect the long-term architecture of the surrounding bone by altering the tooth's internal structure and trabecular pattern (1). The pulp and periodontium are physiologically interconnected via the apical foramen, accessory canals, and dentinal tubules. This establishes a mutual dependence in terms of nutrition and sensory function. Consequently, structural changes or loss of the pulp can induce adaptive modifications in the adjacent bone (2,3). Radiographic follow-up is a reliable and widely used method for moni-

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toring periapical bone healing and evaluating treatment outcomes after dental therapy (4).

Fractal dimension (FD) analysis is a quantitative method used to describe the trabecular architecture of examined tissue (5-7). FD analysis is widely used to evaluate bone healing following endodontic treatment and to study the effects of orthodontic forces on alveolar trabeculation (7,8). Lower FD values indicate higher porosity and voids, while higher values reflect denser, more complex bone structures (9). Furthermore, FD analysis can be applied to panoramic radiographs, eliminating the need for invasive procedures and offering a more accessible and practical alternative to CBCT (6,10).

During orthodontic tooth movement, the alveolar bone undergoes remodeling, with resorption occurring on the pressure side of the periodontal ligament and apposition on the tension side, thereby facilitating tooth displacement within the alveolus. As this process is regulated by cellular mechanisms, pressure and tension regions can develop on both sides of the ligament depending on the type of force applied (11). While the movement of endodontically treated teeth is generally similar to that of untreated teeth, the resorption profiles of the roots may differ. The effects on teeth with apical lesions or a history of periradicular surgery have only been investigated to a limited extent (12-14). In this context, it is important to evaluate the combined impact of endodontic and orthodontic treatments on apical alveolar trabeculation using FD analysis for clinical planning and predicting treatment outcomes (18, 20, 22).

Although no significant difference in the success of endodontic treatment has been reported between males and females (15), sex-related differences have been observed in failure profiles (16). Missed canals and fractured coronal obturations are more prevalent in females, while inadequate obturation and fractured restorations are more prevalent in males (16).

This study aimed to compare changes in the periapical alveolar trabeculation of endodontically treated and healthy mandibular first molars before and after orthodontic treatment using FD analysis. Additionally, the effect of sex on these changes was also explored, and the findings may guide the optimization of treatment strategies at both clinical and microstructural levels. The first null hypothesis states that orthodontic treatment has no adverse effect on the periapical alveolar trabeculation of endodontically treated teeth. The second null hypothesis states that there is no difference in periapical alveolar trabeculation between males and females.

Materials and Methods

Study design, ethics, consent, and sample size calculation

This study was designed as a single-center, retrospective, split-mouth study. The study was approved by the Non-Interventional Clinical Research Ethics Committee of Zonguldak University (No: 2025/20, Date: 19/11/2025) and conducted according to Declaration of Helsinki. Informed consent was obtained from all patients before the study, and no further consent was required due to its retrospective nature.

The sample size was calculated using the G*Power software (version 3.1.9.7, Franz Faul, University of Kiel, Kiel, Germany) based on a paired t-test design (Means: Difference between two dependent means), in accordance with the split-mouth methodology of the study, using data from the study by Akay et al. (3). The effect size was derived from the mean and standard deviation values reported in that study and calculated as dz=0.67. With an α error probability of 0.05 and a desired power of 0.95, the analysis indicated that at least 31 participants were required, yielding an actual power of 0.9551887, with a noncentrality parameter (δ) of 3.7809407 and a critical t value of 2.0422725 (df=30). To ensure homogeneity of sex distribution, a total of 32 patients were enrolled, comprising 15 males (17.13±1.61 years) and 17 females (17.50±1.83 years), with an overall mean age of 17.32±1.71 years.

Groups and criteria

The study included patients who had previously undergone endodontic treatment and completed fixed orthodontic treatment. Using a split-mouth design, each endodontically treated mandibular first molar was assigned to the study group. The contralateral healthy tooth in the same jaw was matched as the control group (Fig. 1).

Patients who did not meet at least one of the predefined inclusion criteria were excluded from the study. The inclusion criteria were as follows:

- Absence of missing teeth, except for third molars;
- Completion of non-extraction fixed orthodontic treatment;
- Presence of a unilateral mandibular first molar that had undergone successful, asymptomatic endodontic treatment at least six months prior to orthodontic treatment;
- Presence of a healthy contralateral mandibular first molar;
- Absence of any systemic disease or condition affecting bone metabolism; and

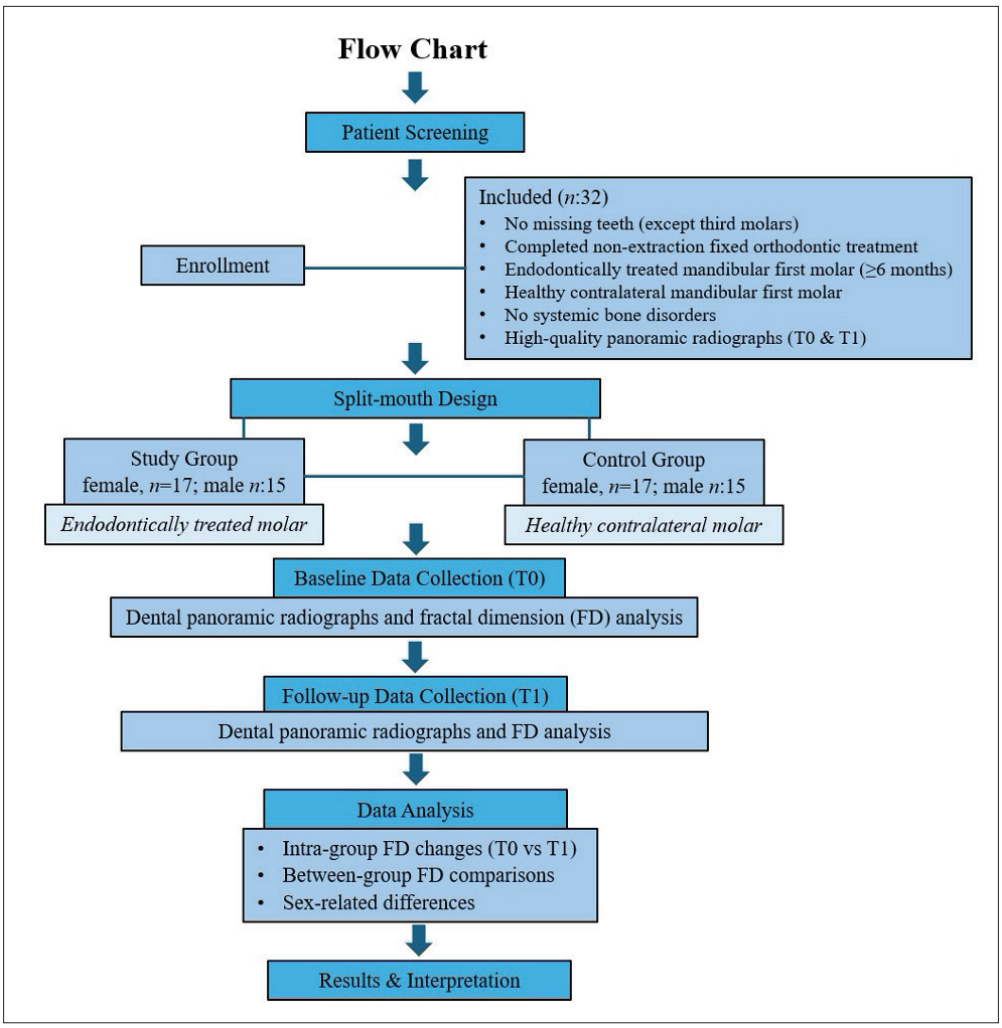

Fig. 1. Flowchart of participants throughout the study.

• Availability of high-quality, high-resolution panoramic radiographs obtained before (T0) and after (T1) orthodontic treatment.

Endodontic ve orthodontic treatment protocols

Endodontic treatments were performed under 3.5× magnification loupes (ADMETEC TTL Galilean 3.5×) with adequate illumination. The target tooth was anesthetized via inferior alveolar nerve block using Maxicaine containing 1:100,000 epinephrine and isolated with a rubber dam. All carious tissues and coronal restorations were removed under water cooling using diamond round and fissure burs, and an endodontic access cavity was prepared. Working length (WL) was determined with #10 and #15 K-type hand files (Dentac) in conjunction with the VDW Gold endomotor and electronic apex locator (VDW GmbH, Munich, Germany) and verified radiographically. Root canals were initially irrigated with 2 ml of 5% Microvem-NaOCl. A reproducible glide path was established using a #15 K-type hand file (Dentac). Shaping was completed with the Endoart rotary file (R25, 25/.06). Final irrigation was performed sequentially with 2 ml of 5% Microvem-NaOCl, 2 ml of Saver-EDTA, and 2 ml of sterile saline. After drying with paper points, obturation was carried out using cold lateral condensation with gutta-percha (EndoArt) and Adseal sealer (Meta Biomed, Korea). Permanent coronal restoration was completed using a composite resin (Dentsply Sirona Inc., Neo Spectra ST™, Charlotte, NC, USA) (17).

Non-extraction fixed orthodontic treatments were performed using stainless steel metal brackets with a 0.022 × 0.028-inch slot and an MBT™ prescription (Mini Master, American Orthodontics, Sheboygan, WI, USA) (18). During the treatment sessions, round 0.014-inch heat-activated nickel–titanium (HANT), 0.016-inch HANT, and 0.016-inch stainless steel archwires were applied sequentially; this was followed by rectangular 0.019 × 0.025-inch

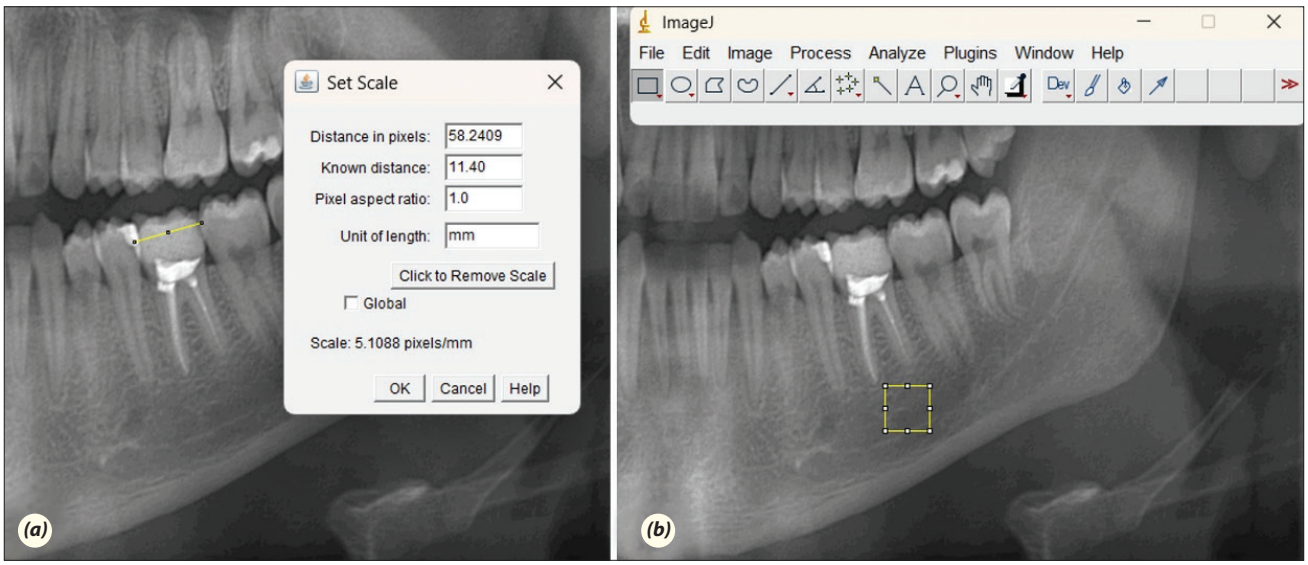

Fig. 2. **(a)** Yellow continuous line: Calibration procedure based on the mesiodistal dimension of a 11.4 mm mandibular first molar. **(b)** Yellow dashed line: A 40×40-pixel ROI selected from the alveolar area apical to the mesial and distal roots of mandibular first molars using ImageJ software.

HANT and rectangular 0.019 × 0.025-inch stainless steel archwires (American Orthodontics, USA), by which the treatment was completed. Orthodontic treatment was initiated at least six months after the completion of endodontic treatment, as defined in the inclusion criteria, to allow for periapical healing. Post-treatment panoramic radiographs (T1) were obtained immediately after the completion of orthodontic treatment. All patients completed non-extraction fixed orthodontic treatment using the same bracket system and standardized archwire sequence, and the total duration of orthodontic treatment was comparable across patients (mean duration: 13±1.5 months).

Radiographic acquisition and fractal dimension analysis

After ensuring the bite stick was properly positioned and aligned with the Frankfurt horizontal plane parallel to the floor, panoramic radiographs were obtained at the T0 and T1 time points using an X-ray unit (Veraviewepocs 2D, J. Morita Mfg. Corp., Kyoto, Japan), operating at 60–70 kVp and 1–7.5 mA. Panoramic radiographs were selected because they are routinely obtained as part of orthodontic records and were readily available for this retrospective study, allowing standardized bilateral assessment with a low radiation dose. Although panoramic images have inherent limitations related to resolution and potential geometric distortion, previous studies have demonstrated that, when standardized acquisition protocols and consistent ROI placement are applied, panoramic radiographs can be reliably used for FD analysis of alveolar bone (3,8,10,19).

Fractal dimension analysis was performed on panoramic radiographs using the box-counting method described by White and Rudolph (20), with ImageJ (version 1.53), which is Java-based image processing software developed by the National Institutes of Health (version 8). All analyses were conducted on an ASUS TUF Gaming F15 FX507ZC4_FX507ZC4 computer (ASUSTeK Computer Inc., Taipei, Taiwan) by a single investigator (OC). FD analyses were performed separately at the T0 and T1 time points. To ensure methodological standardization, the mesiodistal dimensions of the orthodontic study models were measured using a digital caliper (Insize digital caliper, Insize Co., Loganville, GA, USA). Prior to FD analysis, calibration was performed in ImageJ according to the mesiodistal dimensions of the teeth on the panoramic radiographs (Fig. 2a. The FD analysis was carried out by OC, an investigator with at least 11 years of experience in the field and multiple publications on FD analysis (5,6,8,9). The investigator was blinded to the group allocation of the duplicated images during the FD analyses (Fig. 2a, 2b).

ROI positioning was standardized between T0 and T1 by using consistent anatomical reference points in the periapical region of the same tooth. The ROIs were placed at the same relative location apical to the root apex, maintaining identical size and orientation across time points. All ROI selections were performed by the same investigator to ensure consistency. Following calibration, region of interests (ROIs) measuring 40 × 40 pixels were defined in the periapical areas of the mandibular first molars in both the study and control groups (Fig. 2b). After converting

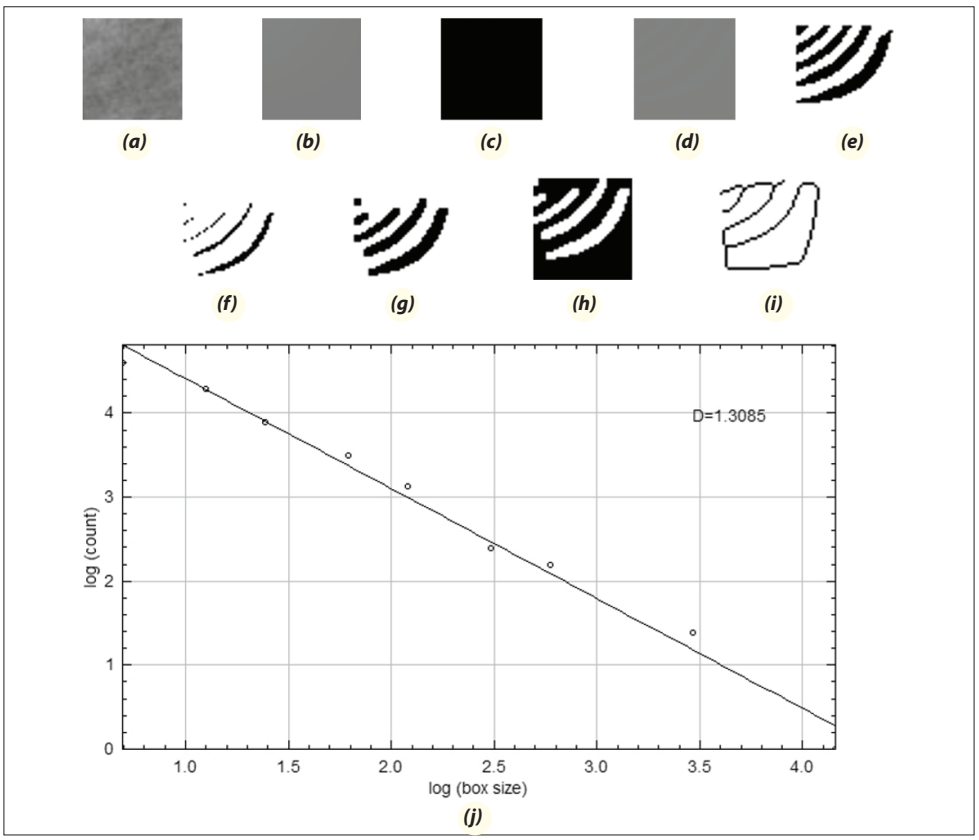

Fig. 3. **(a)** ROI (40 × 40 pixels) extracted from the original panoramic radiograph; **(b)** Gaussian-blurred image; **(c)** image obtained by subtracting the blurred image from the original; **(d)** image adjusted by adding a gray value of 128 (Math); **(e)** binarized image (Binary); **(f)** noise-reduced image after erosion (Erode); **(g)** dilated image enhancing trabecular structures (Dilate); **(h)** inverted image (Invert); **(i)** skeletonized image (Skeletonize); and **(j)** image of fractal box-counting (in image, D: calculated FD value for relevant ROI).

and saving the selected areas in an 8-bit format, a Gaussian blur filter with a sigma value of 35 pixels was applied to the duplicated images to eliminate factors contributing to brightness inhomogeneity, such as soft tissues. Image subtraction from the original image converted the resulting image into binary format by adding a gray value of 128. To minimize image noise, a sequence of image processing steps was performed: Erosion, followed by dilation, then inversion. Next, the skeletonization option was applied to enhance the trabecular bone structure. Finally, a FD value was calculated by performing FD analysis on the skeletonized pattern image using the box-counting method (6) (Fig. 3a, 3b, 3c, 3d, 3e, 3f, 3g, 3h, 3i, 3j).

Statistical Analysis

Statistical analyses were performed using SPSS Statistics software (version 26.0; IBM Corporation, Armonk, NY, USA). The normality of data distribution was assessed using the Shapiro–Wilk test. Considering the split-mouth design, paired t-tests were used for comparisons between the study group and their contralateral controls, as well as for T0–T1 comparisons. Independent t-tests were applied exclusively to evaluate sex-related differences. To evaluate methodological error, the reliability of measurements was assessed by calculating intraclass correlation coefficients (ICCs) based on repeated measurements performed on 20% of the samples at two-week intervals. Effect sizes were calculated using Cohen's d, defined as the mean difference divided by the standard deviation of the paired differences for within-group comparisons. The level of statistical significance was set at $p<0.05$.

Results

The ICC values obtained from repeated measurements ranged from 0.90 to 0.95. These values demonstrate excellent intra-observer reliability, indicating a high level of measurement consistency.

Table 1 presents the FD values for study group teeth and their healthy contralateral control group teeth. At both T0 and T1, FD values of the study group teeth were signifi-

Table 1. Statistical comparison of FD values in study and control groups at T0 and T1 including effect sizes (n=32)

	Study Group Mean±SD (min–max)	Control Group Mean±SD (min–max)	p	Effect size
T0	1.205±0.06	1.32±0.06		
	(1.011–1.312)	(1.175–1.487)	<0.001 * P	1.66
T1	1.273±0.07	1.338±0.06		
	(1.12–1.421)	(1.2–1.492)	<0.001 * P	1.18
T1/T0 FD difference	0.067±0.06	0.017±0.03		
	(-0.079–0.266)	(-0.054–0.098)	<0.001 * P	0.73
Intra-group p	<0.001 * P	0.003 * P		

FD: Fractal dimension. n: sample size. P: paired t-test. min: minimum. max: maximum. T0: before orthodontic treatment. T1: after orthodontic treatment. SD: standard deviation. p: significance level, *: p<0.05.

Table 2. Sex-based inter-group and intra-group statistical analysis results of FD values at T0 and T1

Periods	Sex	Study Group Mean±SD (min–max)	Control Group Mean±SD (min–max)	p
T0	Female (n=17)	1.179±0.07	1.311±0.07	
		(1.011–1.308)	(1.175–1.487)	<0.001 * P
	Male (n=15)	1.236±0.04	1.331±0.03	
		(1.166–1.312)	(1.272–1.409)	<0.001 * P
	Sex difference p	0.014 * t	0.361 t	
T1	Female (n=17)	1.254±0.07	1.326±0.07	
		(1.12–1.421)	(1.2–1.492)	<0.001 * P
	Male (n=15)	1.295±0.05	1.351±0.05	
		(1.222–1.416)	(1.267–1.437)	0.001 *
	Sex difference p	0.107 t	0.313 t	
Groups	**Sex**	**T0 Mean±SD (min–max)**	**T1 Mean±SD (min–max)**	**p**
Study Group	Female (n=17)	1.179±0.07	1.254±0.07	
		(1.011–1.308)	(1.12–1.421)	0.001 * P
	Male (n=15)	1.236±0.04	1.295±0.05	
		(1.166–1.312)	(1.222–1.416)	<0.001 * P
Control Group	Female (n=17)	1.311±0.07	1.326±0.07	
		(1.175–1.487)	(1.2–1.492)	0.041 * P
	Male (n=15)	1.331±0.03	1.351±0.05	
		(1.272–1.409)	(1.267–1.437)	0.039 * P

FD: Fractal dimension. n: sample size; P: paired t-test; t: independent sample t-test; min: minimum; max: maximum. T0: before orthodontic treatment; T1: after orthodontic treatment; SD: standard deviation; p: significance level. *: p<0.05.

cantly lower than those of the control group (p<0.001). However, the amount of FD change from T0 to T1 was greater in the study group teeth (p<0.001). Intra-group comparisons revealed significant increases in FD values from T0 to T1 in both the study group (p<0.001) and the control group (p=0.003). Comparisons between the study and control groups revealed statistically significant differences with large effect sizes at both T0 and T1. While the amount of these differences decreased at T1, the persistence of large effect sizes, together with a moderate-to-large effect size for the T1/T0 FD change, confirms that FD values in the study group remained significantly lower than those in the control group.

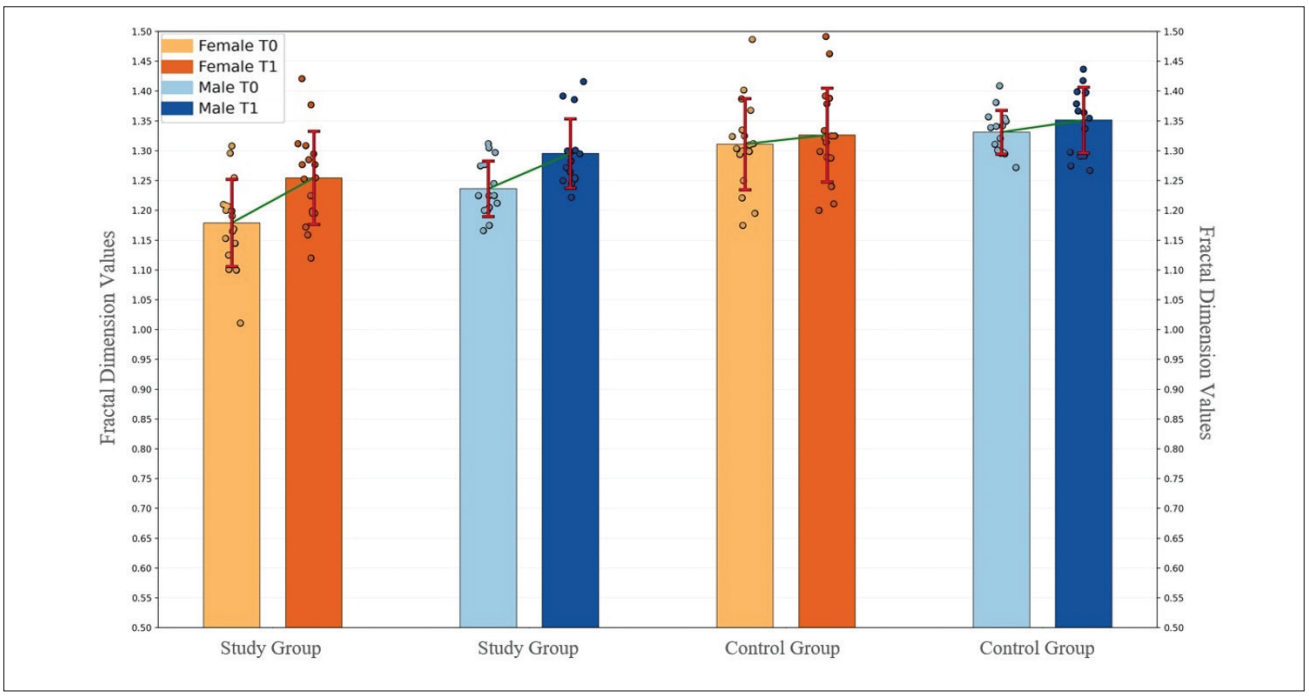

Fig. 4. Changes in FD values over time (T0–T1) according to sex in study and control groups. Small circles: the FD values of each tooth. Red lines: with error bars indicate the mean±standard deviation. Green lines: illustrate changes over time (from T0 to T1).

The FD values of the teeth in the study group were significantly lower than those in the control group for both females and males at T0 and T1 ($p<0.001$). Regarding sex differences, at T0, the FD values of the teeth in the study group were significantly lower in females than in males ($p=0.014$); however, no significant difference was observed in the teeth of the control group ($p=0.361$). Similarly, no significant difference was found between the sexes in the teeth of the study ($p=0.107$) and control ($p=0.313$) groups at T1. Intra-group comparisons from T0 to T1 revealed significant increases in FD values for both study and control groups in both sexes ($p<0.05$) (Table 2). The illustration of changes in FD values in study and control teeth from T0 to T1 according to sex is presented in Figure 4.

Discussion

The FD values of the study group were significantly lower than those of the control group at T0 and T1. However, the increase from T0 to T1 was more pronounced in endodontically treated teeth. Regarding sex, FD values were significantly lower in females than in males at T0; however, this difference was no longer significant at T1. These findings suggest that orthodontic treatment does not cause destructive changes to periapical trabeculation and that the trabecular patterns of endodontically treated teeth tend to resemble those of healthy contralateral teeth during the healing process. Additionally, these results indicate that baseline sex-related differences are balanced throughout the orthodontic treatment period. Accordingly, the first null hypothesis was accepted while the second was rejected at T0 but accepted at T1.

Dental panoramic radiography is one of the most frequently used imaging techniques for detecting jaw- and tooth-related pathologies. It is also used to monitor early and late changes in periapical trabeculation around the root following endodontic and orthodontic treatments (3,7,21,22). Concurrently, FD analysis has gained recognition as an objective, reliable, quantitative method for evaluating trabecular bone microarchitecture (6,7,23). To the best of our knowledge, existing studies on FD analysis have predominantly examined the impact of endodontic (3,7,24) and orthodontic (6,10,19) treatments on trabecular structures in a treatment-specific manner. In contrast, the present study is one of the few to evaluate the combined effects of endodontic and orthodontic interactions on periapical alveolar trabeculation using a split-mouth design. This approach minimizes interindividual variability, allowing for a more accurate and reliable assessment of trabecular bone adaptation following endodontic treatment. Our findings revealed a significant increase in FD values of periapical trabecular bone after endodontic treatment compared with healthy contralateral teeth.

The literature indicates that increases in FD values in the

periapical region following successful endodontic treatment are associated with enhanced trabecular organization related to bone healing (25). Chen et al. (23), reported elevated periapical FD values three months after root canal treatment and interpreted this finding as reflecting early reactive bone formation. However, Yu et al. (24) demonstrated that this dense reactive bone can remodel into a more mature trabecular architecture over time, which can result in a subsequent reduction in FD values. Similarly, Huang et al. (21) observed a significant increase in FD values within the lesion area one year after treatment; however, no significant changes were detected in the unaffected mesial and distal regions. Similarly, Tosun et al. (26) reported increases in FD values within the periapical trabecular bone of teeth undergoing primary endodontic treatment or retreatment when healing occurred, whereas FD values decreased in non-healing cases (7,26). These temporal changes in FD likely reflect early reactive bone formation, followed by progressive trabecular maturation. In our study, increases in FD were observed in both the study and control groups, underscoring the importance of successful endodontic treatment and the application of controlled orthodontic forces to maintain periapical healing during orthodontic treatment.

Studies examining the interaction between orthodontics and endodontics suggest that the quality of the root canal filling and coronal restoration primarily determines periapical healing, while the type, magnitude, and duration of orthodontic tooth movement exert a secondary influence (27-32). Although experimental animal studies have reported that orthodontic forces may temporarily delay healing (33,34), this effect appears to result from transient inflammatory and metabolic changes in the periodontal ligament, reflecting an early-phase biological response (35,36). On the other hand, Konno et al. (27) showed that the histological and hemodynamic changes caused by orthodontic forces in the pulp and surrounding tissues are reversible. Similarly, Alqerban et al. (28) and Kim et al. (29), reported that orthodontic treatment does not adversely affect periapical lesions or radiolucency in teeth with adequate root canal fillings and coronal restorations. These findings align with our observations of a lack of destructive changes in periapical trabeculation during orthodontic treatment. Thus, the increases in FD observed in our analyzed ROIs may reflect biologically adaptive remodeling of the periapical bone in response to controlled orthodontic forces within the context of successful endodontic healing.

It has been reported that sex does not significantly impact endodontic treatment outcomes or periapical healing (37,38). Kim et al. (29) observed more pronounced periapical lesion reduction in females; however, this finding may reflect the gender imbalance in their sample. Similarly, periapical healing has been reported to be more limited in mandibular teeth than in maxillary teeth, likely due to anatomical and biological differences associated with tooth (29,39,40). Ng et al. (37) and the European Society of Endodontology guidelines (41) have also reported that the initial size of periapical lesions significantly influences the healing process. Clinically, our findings indicate that in teeth with successful endodontic treatment, sex-related differences in FD values at baseline do not compromise periapical bone healing under controlled orthodontic forces, and sex alone should not be considered a limiting factor in treatment planning.

A critical limitation of this study is that the FD analysis was conducted using two-dimensional panoramic radiographs, which precluded a direct evaluation of the three-dimensional microarchitecture of the periapical trabecular bone. However, the split-mouth design effectively minimized interindividual biological variability, enabling a reliable comparison of endodontically treated teeth with their healthy contralateral counterparts within the same subject. Future FD studies employing three-dimensional CBCT imaging are necessary to investigate the effects of different orthodontic forces on periapical alveolar trabeculation following regenerative or periapical endodontic surgical procedures.

Conclusion

It was concluded that: (i) Controlled orthodontic forces do not compromise periapical trabeculation in successfully endodontically treated teeth; (ii) increases in FD reflect ongoing bone healing and remodeling; (iii) FD values in endodontically treated teeth converge toward those of their healthy contralateral counterparts, with sex-related differences diminishing over time, indicating that sex is not a determinant factor in periapical healing; and (iv) FD analysis may serve as a valuable tool for monitoring endodontic–orthodontic interactions.

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Conflict of Interest: None declared.

Ethical Approval: The study was approved by the Non-Inter-

ventional Clinical Research Ethics Committee of Zonguldak University (date: 19.11.2025 protocol no: 2025/20).

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

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ORIGINAL ARTICLE

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Research Trends on Fiber Posts in Endodontically Treated Teeth: A Bibliometric Analysis

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Purpose: This study aims to conduct a comprehensive bibliometric analysis of global research trends on fiber post systems used in the restoration of endodontically treated teeth from 1996 to 2025.

Methods: A systematic search was conducted in the Web of Science Core Collection using selected keywords related to fiber-reinforced posts. Only original articles were included. Metadata were exported and analyzed using Biblioshiny (Bibliometrix R-package). Citation-based indicators, co-authorship networks, keyword co-occurrence, and thematic evolution across three time periods (1996–2005, 2006–2015 and 2016–2025) were examined. Citation differences were evaluated using nonparametric statistical tests (Kruskal–Wallis and Mann–Whitney U).

Results: A total of 651 articles were identified. The annual number of publications increased steadily over time, with a peak in 2008 (39 articles). The most productive authors included M. Ferrari and C. Goracci, while Brazil was the most prolific country, followed by Italy, Germany, the United States, and Türkiye. The Journal of Prosthetic Dentistry was the leading source. Keyword analysis revealed a shift from basic bonding and mechanical testing in earlier years toward themes of adhesion, clinical rehabilitation, and dental trauma. Significant differences in citation counts were observed across publication periods ($p<0.001$).

Conclusion: Over the past 29 years, research on fiber posts has evolved from mechanical investigations to more clinically focused applications. The growing global collaboration and thematic shift highlight the maturing nature of this field. These findings can help inform future clinical research and development in post-endodontic restoration.

Keywords: Fiber-reinforced post; endodontically treated teeth; bibliometric analysis; web of science; dental materials.

Introduction

Restoration of endodontically treated teeth poses persistent challenges due to structural weakening caused by loss of tooth structure, altered dentin biomechanics, and the effects of endodontic procedures on moisture content and collagen integrity (1,2). These alterations increase susceptibility to fracture, necessitating reinforcement strategies such as post placement.

Fiber-reinforced posts represent a significant advancement in restorative dentistry, as their elastic modulus closely re-

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sembles that of dentin, promoting more favorable stress distribution and reducing the risk of catastrophic root fractures (3,4). They are composed of unidirectional glass or quartz fibers embedded in a polymer matrix, which allows for improved biomechanical behavior compared to metallic posts (5–7).

Research on fiber posts has expanded considerably over the past two decades, encompassing mechanical testing (push-out, pull-out, bending, fatigue), adhesive evaluations, finite element analysis (FEA), and long-term clinical performance. Mechanical testing has enabled standardized evaluation of bonding effectiveness and fracture resistance (8–10), while FEA has provided insights into stress distribution within restored teeth under simulated functional loads (11,12).

Clinical studies have examined survival rates, types of failures, adhesive strategies, and applications in trauma management, particularly for fragment reattachment in young patients (13,14). However, the literature is highly heterogeneous, making it difficult to assess the evolution of research themes, identify influential authors, or determine collaborative structures.

Bibliometric analysis offers a systematic and quantitative approach to mapping scientific activity, assessing intellectual influence, and tracing thematic evolution within a field (15,16). Such methods have been successfully applied in dental materials and adhesive dentistry to examine publication patterns and research development (17,18).

Unlike previous bibliometric studies that primarily examined fiber-reinforced composites as a broad material category, the present analysis specifically focuses on fiber post systems used in endodontically treated teeth. This post-centered perspective enables a clinically oriented mapping of methodological evolution from bond-strength testing to fracture resistance, survival analysis, and finite-element modeling, identification of leading research groups shaping post-cementation protocols, and evaluation of citation dynamics across distinct technological phases of post-endodontic restoration.

Given the increasing reliance on fiber posts for restorative rehabilitation, a detailed bibliometric assessment is essential to understand how the field has evolved scientifically and clinically. This study aims to evaluate research trends, influential contributors, collaborative networks, and thematic progress in fiber post literature from 1996 to 2025.

Materials and Methods

The bibliometric analysis covered the period from 1996 to 2025. Preliminary verification of the Web of Science Core Collection showed that the earliest indexed publications specifically related to fiber post systems were published in 1996. Including this extended time frame enabled comprehensive coverage of foundational studies and ensured a more accurate evaluation of long-term publication trends, citation patterns, and thematic evolution in the field.The literature search was performed in the Web of Science Core Collection using the following query: TS = ("fiber post*" OR "glass fiber post*" OR "fiber-reinforced post*" OR "fibre post*" OR "glass fibre post*" OR "fibre-reinforced post*") AND ("endodontically treated tooth" OR "endodontically treated teeth" OR "root canal treated tooth" OR "root canal treated teeth"). The Topic (TS) field includes title, abstract, author keywords, and Keywords Plus. The search was limited to original research articles published in English between January 1, 1996 and December 1, 2025. Only original research articles were included, while reviews, conference proceedings, editorials, and letters were excluded.

Records were exported in BibTeX format with complete metadata and cited references and subsequently analyzed using Biblioshiny, the web-based interface of the bibliometrix R package (16). Two independent reviewers screened titles, abstracts, and keywords to confirm relevance, resolving discrepancies through discussion. A calibration phase with 30 articles was conducted to standardize inclusion decisions (19).

Bibliometric indicators including annual publication output, authorship patterns, country contributions, and citation characteristics were assessed. Structural and conceptual analyses included co-authorship mapping, co-citation networks, keyword co-occurrence analysis, and thematic clustering using the Louvain algorithm. Temporal thematic evolution was evaluated by dividing the dataset into three periods: 1996–2005, 2006–2015 and 2016–2025.

Citation distributions were examined using the Shapiro–Wilk test, which demonstrated non-normality. Therefore, Kruskal–Wallis and Bonferroni-adjusted Mann–Whitney U tests were used. Ethical approval was not required because publicly accessible bibliographic data were used.

Results

A total of 651 original research articles were identified for the 1996–2025 period. The overall publication volume exhibited a steady upward trend, with marked increases beginning in the mid-2000s and peaking in 2008 (39 publications) (Fig. 1). Earlier studies accumulated more citations, reflecting both foundational influence and the expected citation lag.

The distribution of author productivity is presented in Table 1, highlighting the dominance of Ferrari, Goracci,

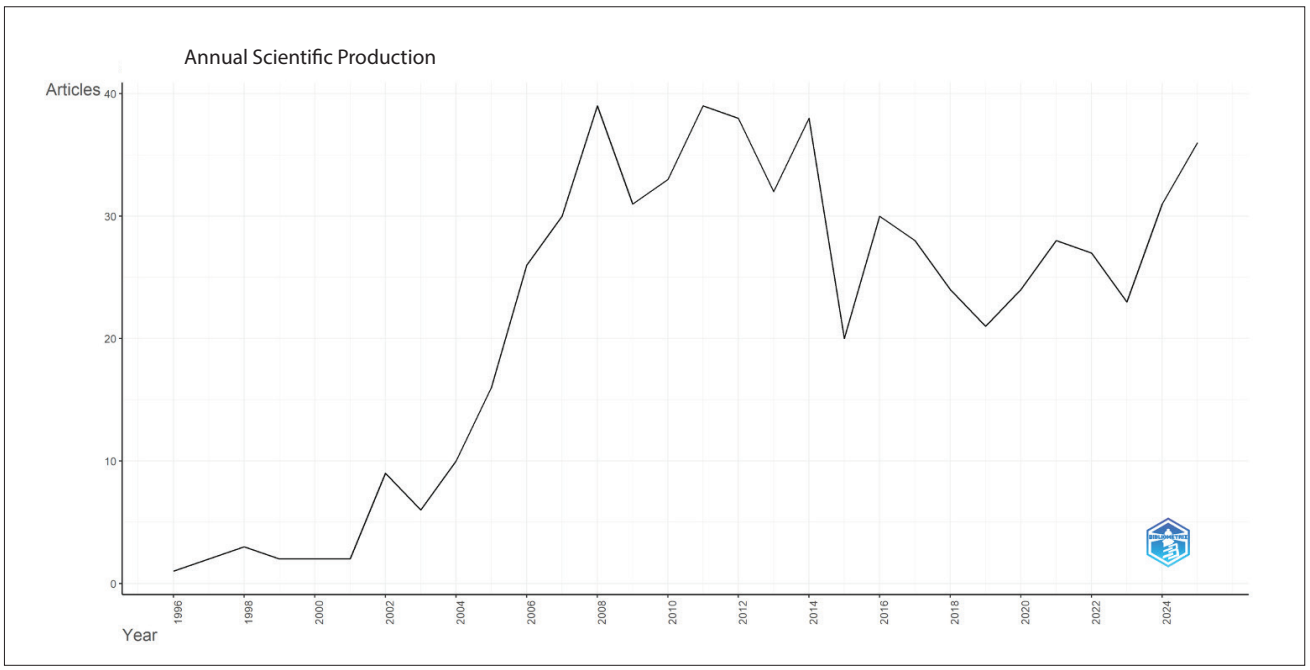

Fig. 1. Annual scientific production in fiber post research (1996–2025).

Table 1. The top 10 most productive authors in fiber post–related research between 1996 and 2025, according to the Bibliometrix author productivity analysis

Rank	Author	Documents (n)	Country	Main Research Area
1	FERRARI M	62	Italy	Adhesion, post-endodontic restoration
2	GORACCI C	29	Italy	Bond strength, fiber post adhesion
3	MONTICELLI F	20	Italy	Adhesive systems, resin cements
4	NAUMANN M	19	Germany	Post–core restorations, biomechanics
5	GRANDINI S	16	Italy	Fatigue resistance, fiber post mechanics
6	VALANDRO LF	14	Brazil	Mechanical behavior, fracture resistance
7	BITTER K	13	Germany	Endodontic-restorative procedures
8	GARCIA-GODOY F	13	USA	Adhesive dentistry, restorative materials
9	RADOVIC I	12	Serbia	Resin cements, post systems
10	TAY FR	12	USA	Biomaterials, dentin bonding

Monticelli, Naumann, and Grandini. Ferrari was the most prolific author, followed by Goracci, Monticelli, Naumann, and Grandini. These researchers frequently collaborated and played central roles in generating knowledge on adhesive strategies, mechanical performance, and stress distribution.

Brazil ranked as the leading contributor, followed by Italy, Germany, the United States, and Türkiye (Fig. 2). Brazil's prevalence is consistent with its strong research base in adhesive dentistry and restorative materials. Italy's influence reflects the output of highly productive academic centers, while contributions from China and Türkiye indicate global expansion of interest.

The Journal of Prosthetic Dentistry published the highest number of articles, followed by the Journal of Dentistry, Journal of Endodontics, Journal of Adhesive Dentistry, and the International Endodontic Journal.

The thematic map further illustrated these conceptual transitions by positioning major research themes according to their centrality and degree of development (Fig. 3). Four main thematic clusters were identified: (i) a motor theme centered on microtensile testing and adhesive

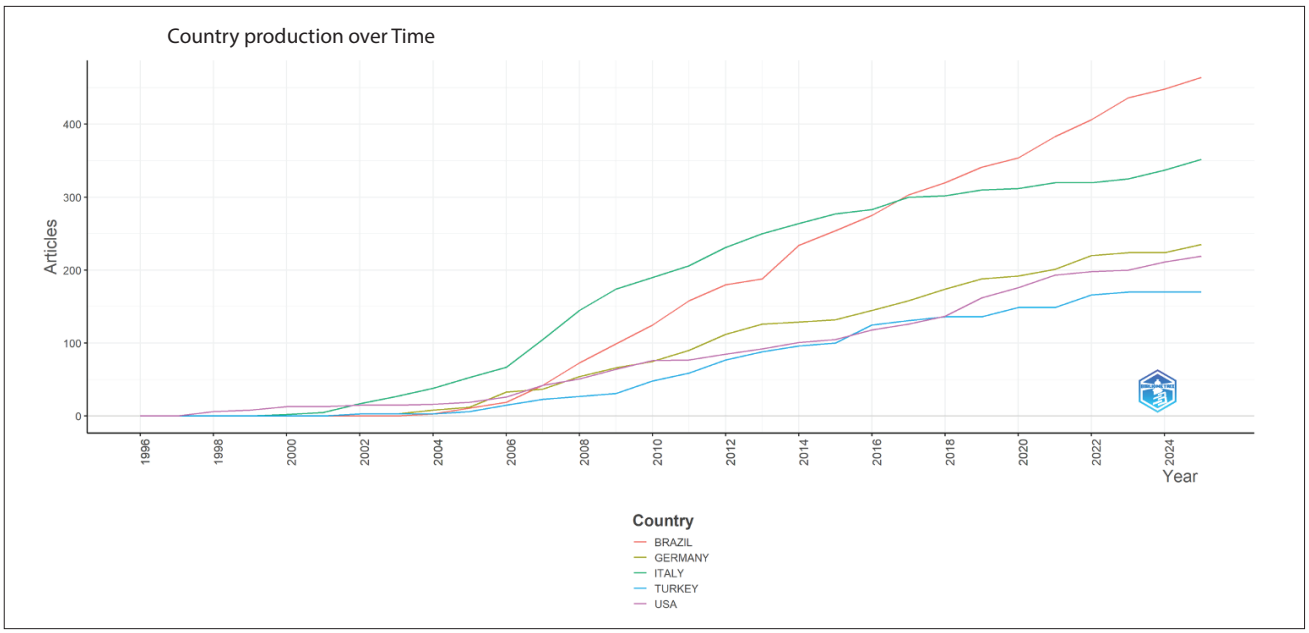

Fig. 2. Country production over time in fiber post research (1996–2025).

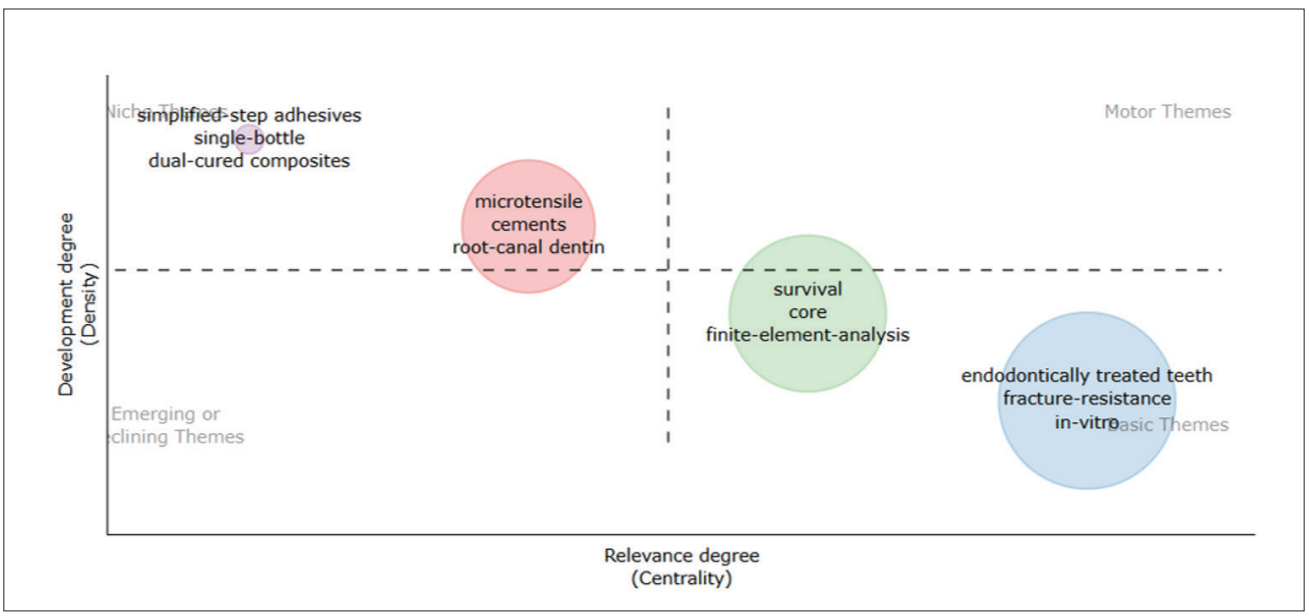

Fig. 3. Thematic map of fiber post research based on keyword co-occurrence analysis.

interfaces (including "microtensile," "cements," "root-canal dentin," "adhesion," and "adhesive"), reflecting the methodological core of bonding evaluation in fiber post research; (ii) a second highly central cluster focused on "endodontically treated teeth" and fracture resistance–related terms, representing clinically driven restorative performance outcomes; (iii) a specialized but moderately developed cluster related to simplified adhesive strategies (e.g., "simplified-step adhesives," "single-bottle," and "dual-cure systems"), indicating ongoing optimization of cementation protocols; and (iv) a transversal survival-oriented cluster comprising "survival," "core," and "finite-element analysis," highlighting the integration of long-term clinical performance assessment with biomechanical modeling approaches as emerging integrative directions.

Keyword analysis revealed a shift from early laboratory-

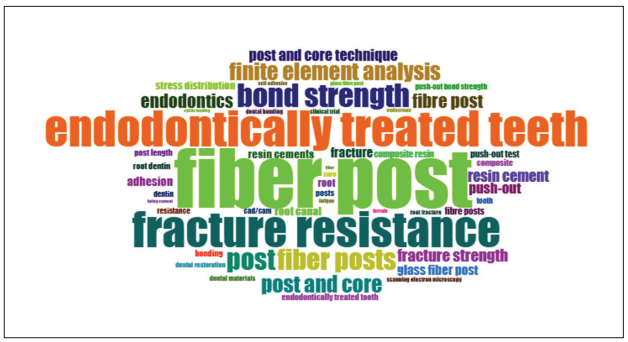

Fig. 4. Word cloud of the most frequent keywords in fiber post research.

focused concepts such as "push-out test," "bonding," and "finite element analysis" toward clinically oriented terms including "fracture resistance," "post-endodontic rehabilitation," and "dental trauma." Figure 4 illustrates the most frequent keywords in the dataset, highlighting the dominant focus on fiber posts, fracture resistance, and adhesive performance.

Trend topic analysis demonstrated a clear temporal shift in the scientific focus of fiber post research. Early studies (2002–2008) predominantly addressed material-related parameters such as sealing ability, carbon-fiber posts, reinforcement, and microscopic evaluation techniques. During the intermediate period, keywords related to survival rate, fracture strength, and restorative design became more prominent, reflecting a transition toward clinical performance assessment. In recent years (after 2019), research interest has increasingly focused on biomechanical behavior, the ferrule effect, composite resin restorations, single-crown applications, and accuracy, indicating a maturation of the field toward clinically integrated, biomechanically optimized treatment concepts.

Co-authorship networks identified Ferrari's group as a central hub of international collaboration. Co-citation networks emphasized the influence of Grandini's mechanical investigations and Dietschi's biomechanical and restorative frameworks.

Citation counts differed significantly across the three publication periods ($p<0.001$). The median number of citations decreased from 77 in 1996–2005 to 23 in 2006–2015 and 7 in 2016–2025 (Table 2). Pairwise comparisons using the Mann–Whitney U test confirmed statistically significant differences between all period pairs ($p<0.001$).

Discussion

The results of this bibliometric analysis demonstrate a clear evolution in the themes and methods of fiber post research over the past 29 years. Early studies focused on understanding the biomechanical and adhesive behavior of fiber posts, comparing them with metal posts, and establishing reliable mechanical testing methods. These foundational investigations provided the methodological infrastructure still used in modern research (20–22).

As adhesive dentistry advanced, research shifted toward improving interfacial durability, optimizing resin cements, and enhancing long-term bonding performance. Simplified adhesive systems, improved polymerization kinetics, and enhanced resin matrices contributed to the transition from laboratory-centered evaluations to clinically oriented investigations (23,24).

Thematic analysis revealed a broader integration of fiber posts into minimally invasive restorative dentistry, including fragment reattachment, tooth reinforcement, and management of dental trauma. This shift reflects increasing recognition of the biomimetic and esthetic advantages of fiber posts in contemporary restorative approaches. The central role of highly productive authors including Ferrari, Goracci, Monticelli, Naumann, and Grandini underscored the influence of a small number of key research groups. Their contributions spanned laboratory testing, adhesive system development, biomechanical simulation, and clinical application, forming the intellectual backbone of the field (25–28). Co-citation networks highlighted the continued relevance of Grandini's fatigue and structural studies, as well as Dietschi's comprehensive biomechanical analyses (8,29,30).

Beyond thematic developments, this bibliometric analysis also highlights significant geographic and citation-based trends that mirror patterns reported in other areas of

Table 2. Comparison of citation counts across three publication periods (1996–2005, 2006–2015, 2016–2025).

Publication Period	n (Articles)	Median Citations (IQR)	Kruskal–Wallis (H)	p-value	Pairwise Comparison	Mann–Whitney U	p-value
1996–2005	53	77 (35–157)			1996–2005 vs 2006–2015	13,990.0	<0.001
2006–2015	326	23 (11–45)	195.24	<0.001	1996–2005 vs 2016–2025	13,527.0	<0.001
2016–2025	272	7 (2–16)			2006–2015 vs 2016–2025	67,987.5	<0.001

IQR: interquartile range; H: Kruskal–Wallis test statistic.

dental biomaterials research. Brazil emerged as the most productive country in the fiber post literature, followed by Italy, Germany, the United States, and Türkiye. This dominant contribution by Brazil is consistent with bibliometric studies in adhesive dentistry, composite resins, and dental materials, in which Brazil has repeatedly ranked first in global publication output (17,31,32). The country's strong academic infrastructure, high density of dental postgraduate programs, and emphasis on adhesive and restorative research likely explain its prominent position. Italy's high output is similarly unsurprising, given the central role of Ferrari, Goracci, and their collaborators, whose work has shaped the conceptual foundation of fiber post science for more than two decades. Their influence, reflected in co-authorship and co-citation patterns, mirrors findings from bibliometric studies of intraoral scanners and ceramic materials, where small but prolific European groups also shaped early research trajectories.

Importantly, the concept of "global trends" in fiber post research extends beyond geographic productivity patterns and is more accurately reflected in the worldwide evolution of research topics. Trend topic analysis revealed a consistent thematic progression across different regions, from early material-centered investigations toward clinically and biomechanically driven research priorities. This shared transition suggests that the development of fiber post science has followed a common global trajectory, shaped by advances in adhesive dentistry, restorative strategies, and digital technologies, rather than being dominated by isolated regional research agendas.

Citation dynamics across the 29-year period further reveal how fiber post research has matured. The highest citation accumulation was observed for articles published between 1996 and 2005, despite the relatively lower publication volume during this early phase of the field. This pattern is consistent with the well-documented "citation time window effect," whereby foundational studies benefit from longer exposure and consequently accrue disproportionately higher citation counts (33,34). In the present study, the median citation count declined markedly across subsequent periods, from 77 citations in 1996–2005 to 23 in 2006–2015, and further to 7 in 2016–2025. This pronounced decrease reflects not only the limited time available for recent publications to accumulate citations, but also a progressive diversification of research topics and methodological approaches, which disperses scholarly attention across a broader range of studies rather than concentrating citations on a small number of seminal works.

Interestingly, the temporal distribution of highly cited studies also mirrors major technological and conceptual transitions within the field of post-endodontic restoration. The first prominent citation peak, corresponding to the late 1990s and early 2000s, coincides with the widespread clinical adoption of fiber posts, the standardization of push-out and microtensile bond strength testing protocols, and the early comparative evaluation of adhesive systems. These developments laid the methodological foundation of contemporary fiber post research and generated a cluster of highly influential publications.

A second, more moderate rise in citation activity during the mid-2010s parallels the growing focus on adhesive durability, fatigue resistance, novel resin cement formulations, and the routine incorporation of finite element modeling into biomechanical assessment and restorative decision-making.

Following 2020, a marked decline in citation accumulation is observed, primarily due to the limited citation time window for recent publications. This trend may have been further amplified by the COVID-19 pandemic. The observation that peak citation periods occur early, while publication volume peaks later, is consistent with other bibliometric fields, including dental ceramics, CAD/CAM prosthodontics, and adhesive dentistry. In these fields, foundational scientific questions are published early, while later work becomes more specialized and thereby accumulates fewer citations (35). This suggests that the conceptual core of fiber post research was largely established during the first decade, with subsequent studies refining, optimizing, and clinically translating these early principles rather than introducing disruptive conceptual paradigms.

Taken together, the geographic distribution and citation trends reinforce the interpretation that fiber post research has undergone an initial "foundational expansion phase," followed by a "maturation and diversification phase," a developmental pattern that parallels the historical trajectory of other major dental material innovations. Understanding these dynamics offers a valuable perspective for guiding future research emphasis toward clinically meaningful, long-term, and interdisciplinary investigations that can reinvigorate the field and address remaining gaps in adhesive stability and biomechanical predictability.

Despite substantial progress, challenges persist, including improving long-term bond durability, minimizing debonding, the most common failure mode, and validating laboratory findings through clinical trials. Emerging technologies, such as CAD/CAM-customized fiber posts, nanofiber reinforcement, and bioactive resin cements, offer promising avenues for future improvement but require clinical validation, a trend consistent with the recent shift toward durability and performance-oriented research themes identified in the thematic evolution analysis.

This study has several limitations. Although the Web of

Science Core Collection offers reliable bibliographic data, some relevant studies indexed in Scopus and PubMed may not have been included. Citation indicators are also influenced by publication time and tend to favor earlier articles. In addition, the effects of self-citations, journal-specific citation practices, and minor variations in keyword usage cannot be entirely excluded.

Conclusion

This bibliometric analysis identifies major trends in the evolution of fiber post research from 1996 to 2025. The field has progressed from foundational biomechanical investigations to clinically focused, interdisciplinary approaches that emphasize adhesion optimization, restorative longevity, and minimally invasive strategies. Early studies continue to exert substantial influence, as reflected in their citation performance.

Future research should prioritize long-term clinical trials, standardized protocols, and the integration of advanced restorative and digital technologies to address persistent challenges and enhance the predictability of post-endodontic rehabilitation outcomes.

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ORIGINAL ARTICLE

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Effectiveness of Silver Diamine Fluoride for Arresting and Preventing Root Caries in Older Adults: A Systematic Review and Meta-Analysis

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Purpose: Amidst increasing gingival recession, xerostomia, and poor access to restorative care, root caries has emerged as an important concern in older adults. Silver diamine fluoride (SDF) is the most applied minimally invasive approach for the arrest and prevention of caries, but there is still debate over its efficacy on teeth among geriatric individuals. This review aimed to examine the effectiveness of SDF in arresting and preventing root caries in adults aged ≥55 years compared to a placebo, no treatment, or other topical agents.

Methods: A systematic review and meta-analysis were carried out according to PRISMA 2020 guidelines and a previously registered protocol (PROSPERO CRD420251231424). A literature search in PubMed, Embase, Web of Science, and Scopus from the database inception until November 2025 was carried out. The search included studies that examined SDF for the arrest or prevention of root caries in older adults; therefore, randomized controlled trials, quasi-experimental studies, and cohort studies were considered. Study selection, data extraction, and risk of bias assessment were conducted independently by two reviewers, using RoB 2.0 and the Newcastle-Ottawa Scale. Random-effects models were used to determine the standardized mean differences (SMD) and odds ratios (OR) with 95% confidence intervals (CI). I^2 was used to quantify heterogeneity, and Doi plots and the LFK index were used to assess publication bias.

Results: A total of eleven studies met the inclusion criteria (n=1,958 participants). The pooled SMD did not show any statistically significant difference between SDF and placebo for arresting root caries (SMD −0.02; 95% CI −0.15 to 0.11; I^2=98.9%). Similarly, pooled dichotomous data showed no significant association between SDF and caries arrest (OR 0.60; 95% CI 0.26–1.41; I^2=91.9%). Substantial heterogeneity and asymmetry in the Doi plot suggested methodological differences and potential publication bias.

Conclusion: Available evidence does not show consistent benefit of SDF over placebo or other preventive agents in arresting root caries among older adults. Considerable heterogeneity, methodological limitations, and small-study effects restrict the certainty of current findings. Well-designed multicentre randomized trials with standardized protocols, defined application intervals, and ≥24-month follow-up are required to clearly establish SDF effectiveness in geriatric populations.

Keywords: Silver diamine fluoride; root caries; older adults; geriatric dentistry; caries arrest.

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Introduction

Root caries has become one of the most prevalent conditions in the geriatric population. With increasing life expectancy worldwide, decreasing rates of complete edentulism, and retention of natural dentition into advanced age, the burden of root-surface disease increases among older adults (1,2). Literature data show that more than 50% of community-dwelling elders and up to 70% of those in long-term care have at least one active root caries lesion, whereas incidence rates increase steeply after age 70 years due to gingival recession, xerostomia, multimorbidity, and polypharmacy (3–5). In contrast to coronal caries, root caries progresses faster because dentin has a lower mineral content and a higher organic composition, and lesions often appear in difficult-to-reach areas, which complicates detection and restoration (6). The complicating factors in addressing root caries risk in older adults include functional limitation, reduced salivary flow, cognitive impairment, and limited access to routine dental services, especially among institutionalized populations (7,8).

Conventional restorative approaches, however, offer only temporary benefit and may result in a restoration-replacement cycle in which each successive intervention removes incrementally more tooth structure and heightens the risk for an ultimate tooth loss (9). In contrast, non-invasive and minimally invasive strategies that arrest disease and prevent new lesion development are increasingly recognized as the linchpin of geriatric oral health care. Silver diamine fluoride (SDF) has gained widespread international attention as a simple, inexpensive, non-surgical agent effective in both arresting and preventing caries. A combination of silver, fluoride, and ammonia, SDF exerts an antibacterial, remineralizing, and collagen-stabilizing action well-suited for high-risk and medically complex patients (10,11). Its mechanism involves the precipitation of both silver compounds and fluorapatite in demineralized dentin, the antimicrobial suppression of cariogenic biofilm, and the inhibition of matrix metalloproteinases responsible for the degradation of dentin collagen (12,13).

While there is extensive evidence for the effectiveness of 38% SDF in arresting coronal caries among children, evidence related to its use in the management of root caries among older adults is much less clear. Several randomized trials reported annual application of SDF to yield an arrest rate of over 60% (14,15), while others evidenced limited or no additional benefit over placebo or fluoride varnish (16,17). Heterogeneity in application frequency, diagnostic criteria, lesion activity, follow-up duration, and patient population characteristics has led to difficulties in drawing firm conclusions on its real-world effectiveness with regard to geriatric dentistry. A review by Gao et al. (4) indicated that SDF might therefore be more effective when applied at 6-monthly intervals, especially in institutionalized elders with high disease burden; however, the certainty of the evidence remains low because of serious methodological limitations and due to a lack of consistent outcome reporting. Moreover, aesthetic issues associated with blackening may, although of reduced relevance to root surface lesions, also impact acceptance by patients and carers (18).

Given the growing demand for non-restorative treatment options in older adults, there is a need for a critical appraisal of the evidence for SDF specifically related to root caries. Prior reviews have combined coronal and root caries, included younger populations, or used broad inclusion criteria, thereby overestimating effectiveness. The present systematic review and meta-analysis have targeted, for the first time, older adults (≥55 years) with root-surface caries, comparing SDF with either a placebo, no treatment, or alternative topical agents using prevailing methodological standards. By systematically appraising contemporary clinical evidence, this review aims to establish the clinical utility of SDF in treating root caries in older adults and to outline its effectiveness, uncertainties, and implications for evidence-based geriatric dental care.

Materials and Methods

This systematic review and meta-analysis were conducted to study effectiveness of silver diamine fluoride for arresting and preventing root caries in older adults. The review followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 guidelines (Appendix Table S1) (19), and the protocol was prospectively registered in the International Prospective Register of Systematic Reviews (PROSPERO; ID CRD420251231424) database to maintain transparency, methodological rigor, and reproducibility.

Eligibility criteria

Studies were considered eligible if they investigated the effectiveness of silver diamine fluoride (SDF) for the arrest or prevention of root caries in older adults. Eligible populations included community-dwelling or institutionalized individuals aged 55 years or older who presented with active, incipient, or at-risk root-surface caries on permanent teeth. The intervention of interest was the topical application of SDF in any concentration, used alone or as part of a standard oral-care regimen. Comparators included placebo, no treatment, or alternative topical preventive agents such as fluoride varnish, high-fluoride toothpaste, or chlorhexidine varnish. Studies were required to report quantitative clinical or radiographic outcomes reflecting caries arrest or the

prevention of new root-surface lesions. Randomized controlled trials, quasi-experimental studies, and prospective or retrospective cohort investigations were eligible for inclusion. Reports limited to case descriptions, small series with fewer than ten participants, in-vitro or animal experiments, reviews, editorials, and conference abstracts were excluded. Only full-text, peer-reviewed articles published in English through November 2025 were included (Appendix Table S2).

Literature Search

Four major databases were searched electronically: PubMed, Embase, Web of Science and Scopus. The purpose of this was to find original studies that were investigating the effectiveness of the SDF as an arresting or prevention of root caries in older adults. Both controlled vocabulary and free-text terms based on the search terms: silver diamine fluoride, root caries, and older adults were used to search each database since its inception up until November 2025. The PubMed search approach involved Medical Subject Headings (MeSH) of "silver diamine fluoride" and "root caries", as well as the use of text words indicating the root-surface lesions and "aged populations". Similar search terms were tailored to each database by its indexing scheme, such as Emtree terms in Embase and topic fields in Web of Science and Scopus. They used Boolean operators and truncation symbols (such as root cari* or elder*) to ensure that they got as many retrievals as possible and those variations in terminology. Articles in English language were considered only at this point (Appendix Table S3). The search strategy was narrowed down through an iterative process to balance sensitivity and precision, and to select all the potentially relevant publications for screening.

Screening and Data extraction

The search results of the databases were all exported in Research Information Systems (RIS) format and imported to the Nested Knowledge (NK) platform to screen and manage the data. The first step involved the automatic identification and removal of duplicate records in the software, and then manual confirmation. The process of screening the studies was conducted in two steps: First, titles and abstracts were screened, after which the full-text assessment was performed to decide whether a study is eligible based on the predefined set of inclusion criteria. The stages were carried out separately by two reviewers with any differences only addressed in a discussion with a third reviewer to maintain objectivity and methodological rigor. Data extraction was also conducted independently by two reviewers in the form of standardized forms in the context of NK. The information that was extracted was the characteristics of the study, the demographic of the study participants, the criteria of the diagnosis, the study design and the prevalence estimates. Any extracted information was subjected to a final check to verify its accuracy and completeness and then subjected to quantitative synthesis.

Quality assessment

Two reviewers independently rated the methodological quality and risk of bias of the included studies using tools depending on the study design. In the case of randomized controlled trials, Cochrane Risk of Bias 2.0 was applied (20). The framework evaluates possible bias in the process of randomization, non-conformity to planned interventions, outcome data completeness, measurement reliability, and selective reporting. The Newcastle Ottawa Scale (NOS) came in handy with respect to observational studies, such as cross-sectional, cohort, and case-control design (21). This tool is used to assess three areas, which are the sufficiency of the selection of the participants, the similarity of the groups studied, and the precision of exposure or result measurement. In every study, a maximum of nine points would be possible; 7-9 would be high quality, 4-6 moderate quality, and below would be low quality. The differences among reviewers were also discussed, and consensus was agreed upon before scoring was done to achieve objectivity and methodological rigor. Appendix Table S4, and Figure S1 demonstrated in detail quality assessment rating.

Statistical analysis

For the statistical analysis, R, version 4.4.0 has been used, and meta-analytic calculations were carried out with the help of the meta and 'metagen' packages. SDF effectiveness with regard to arresting root carries among elderly people was measured using odds ratios (ORs) with 95% CI. SMD were utilized in estimating the effectiveness of SDF in intervention and placebo or control group. To explain the anticipated heterogeneity of study designs and populations, a random-effects model was used. Heterogeneity was evaluated using I^2 statistic with values of 25%, 50%, and 75% indicating low, moderate, and high levels, respectively. Statistical significance was defined at a 2-sided $P < .05$. Publication bias was evaluated using Doi plots and quantified with the Luis Furuya-Kanamori (LFK) index, where values between -1 and +1 indicated no asymmetry, ±1 to ±2 suggested minor asymmetry, and values beyond ±2 indicated major asymmetry (22).

Due to the expected clinical and methodological differences between studies, such as silver diamine fluoride concentration, number of applications, duration of follow-up after applications, criteria used to diagnose root caries activity,

and type of setting where recruits were obtained—a random-effects model was chosen apriori. Although there appeared to be considerable heterogeneity (I^2>90%), neither formal tests for differences between subgroups nor meta-regression were performed because very few studies were eligible for each covariate and data were inconsistent regarding potential modifiers of observed effects. Under such circumstances, statistical power would be insufficient and results potentially spurious for either tests for differences between subgroups or for regression models (23,24).

Despite being essentially a binary outcome in practice, in cases where studies were measuring outcomes associated with caries arrest, severity, or activity on a continuous or composite basis that could not be calculated as a binary outcome without discarding valuable data, standardized mean differences were utilized. Where available, odds ratios with 95% confidence intervals were calculated and pooled to improve their utility. Analyses were also performed separately on both SMDs and ORs, and results interpreted on the basis of estimates from the binary outcome in each pair of studies selected from the literature according to the initial protocol and review of their pooled estimates on sensitivity and risk of bias assessment in sensitivity analyses to assess the stability of pooled estimates of effect in removing studies considered to have high bias in their assessment.

Standardized mean differences (SMDs) were used for continuous or composite outcomes of caries arrest measured with different scales. In these cases, risk ratios or risk differences were not applicable because these measures are defined for binary outcomes. If continuous outcomes had been treated as binary, it would have been necessary to apply arbitrary cut-offs to these values, which would complicate accurate assessment of outcomes. Therefore, SMDs were used to allow for comparison of outcomes independently of their scales. If caries arrest occurred as a binary variable, odds ratios were derived and given higher preference for assessment Although subgroup analysis based on application frequency and setting is of interest, such analysis has not been carried out due to the paucity of studies reporting these factors with reasonable homogeneity and lack of sufficient data in these subgroups to make valid inference by statistics (25).

Results

Literature search

We searched PubMed, Embase, Scopus and Web of Science from inception through November 2025 for studies evaluating fluoride exposure and root caries in older adults. The initial search retrieved 402 citations (Fig. 1), 169 yielded upon removal of duplicates, 233 unique records were screened by title and abstract. Of these, 213 were excluded because they were unrelated to the study question (n=159), were review articles (n=48), or were case reports, guidelines, or editorials (n=6 in total). Twenty full-text articles were assessed for eligibility, and nine were excluded due to the absence of relevant outcome data (n=2), qualitative study design (n=2), or lack of accessible full text (n=5), resulting in 11 studies included in the systematic review (14–17, 26–32).

Summary characteristics of included studies

A total of eleven studies were included in the review. The studies were conducted across diverse geographic regions, includes Sweden, United States, China, Thailand, and India, reflecting a broad international representation of older adult populations (Table 1). The included studies used a mix of prospective and retrospective cohorts, randomized clinical trials, and one cross-sectional design. Sample size and mean age included sample size ranged from 30 to 486 and 57 to 104 years, respectively. The female proportion is roughly 45% to 78% of the participants across studies. The primary outcome was the ability of silver diamine fluoride (SDF) to arrest root-surface caries. Although study designs differed, all investigations assessed SDF as a preventive or therapeutic option for controlling root caries in older adults.

Effect of Silver Diamine Fluoride on Root Caries Arrest

Seven randomized clinical trials assessed SDF versus placebo for the arrest of root caries in older adults. The pooled random-effects estimate of SMD was −0.02 (95% CI, −0.15 to 0.11), indicating no significant benefit of SDF over placebo. There was marked heterogeneity among the studies (I^2 = 98.9%; P<0.001) (Fig. 2), attributable to differences in SDF concentration, frequency of application, the outcome assessed, and participant features. Together, these suggest that the current evidence is not conclusive and that larger trials with rigorously standardized treatment protocols are required to establish the clinical efficacy of SDF in arresting root caries in this age group.

Leave-one-out evaluation demonstrated that the pooled estimate did not change importantly after exclusion of any single study. The SMD was −1.77 (95% CI, −4.61 to 1.06), and its direction or size did not change importantly after removal of any single study (Fig. 3). Such a finding suggests stability for the overall result despite substantial heterogeneity across the studies.

Based on effect sizes from primary studies of older adults, the association of SDF application with arrest of root caries was assessed. Of these, two studies showed statistically

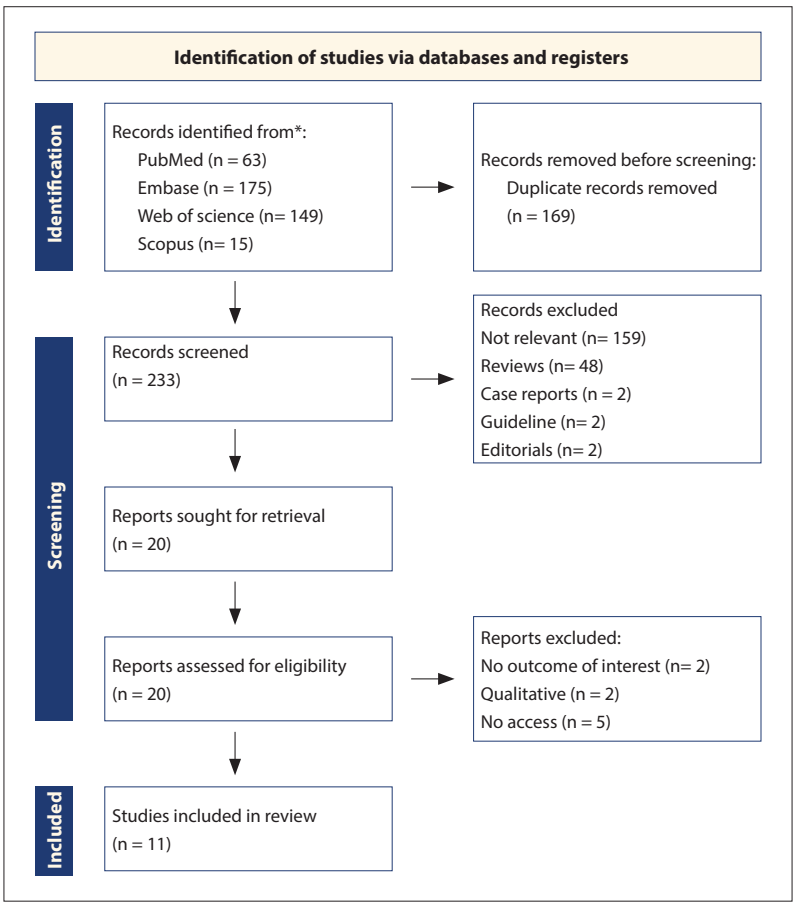

Fig. 1. PRISMA flow chart depicting the study inclusion process.

Table 1. Summary of study characteristics

Study	Country	Study design	Sample size	Mean age	Female percentage	Outcomes measured	Quality Assessment (NOS score/RoB)
Kettelkamp, et al. (26)	USA	Retrospective cohort	169	65–104	45.1	SDF; arresting root caries	8
Detsomboonrat, et al. 2024 (27)	Thailand	Prospective study	98	57- 83	53.1	SDF; arresting root caries	7
Nakphu, et al. (28)	Thailand	Cross-sectional	486	65.3	52.7	SDF; arresting root caries	7
Ericson, et al. (14)	Sweden	Randomised clinical trial	356	87.7	76.7	SDF; arresting root caries	Some Concerns
Noureldin, et al. (29)	USA	Randomized, controlled, double-blinded pilot trial	30	70.1	67.2	SDF; arresting root caries	Some Concerns
Tan, et al. (30)	USA	Randomized clinical trial	155	78.8	76.5	SDF; arresting root caries	Low Risk
Zhang, et al. (15)	China	Prospective randomized controlled clinical trial on a cohort	182	72.5	74.4	SDF; arresting root caries	Low Risk
Li, et al. (17)	China	Randomized clinical trial	75	72.2	75.9	SDF; arresting root caries	Low Risk
Bhat, et al. (16)	India	A parallel group randomised clinical trial	53	71.3	55.2	SDF; arresting root caries	Low Risk
Li, et al. (31)	China	Randomized clinical trial	215	72.1	78	SDF; arresting root caries	High Risk
Chan, et al. (32)	China	Double-blind randomised controlled clinical trial	139	70.4	56.8	SDF; arresting root caries	Low Risk

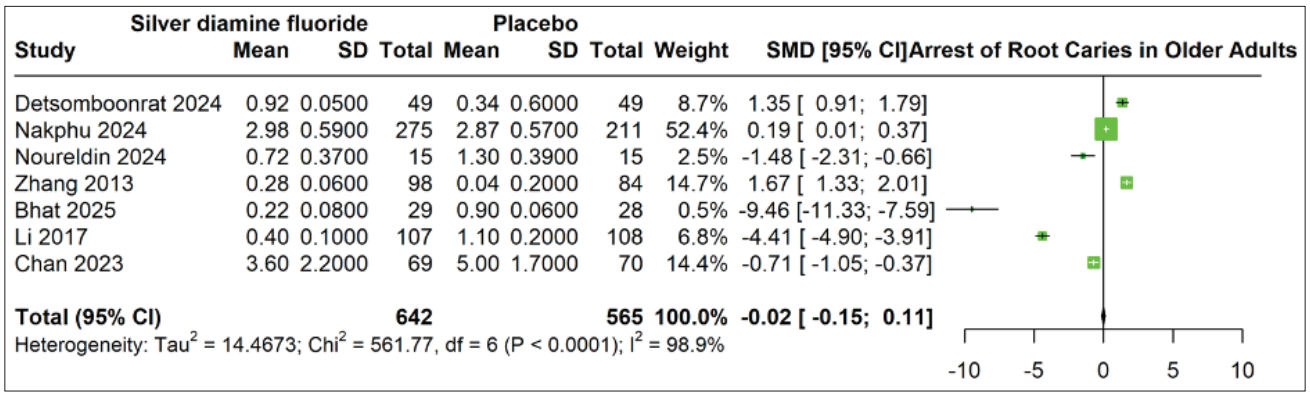

Fig. 2. Forest plot showing Arrest of root caries in older adults with silver diamine fluoride vs placebo.

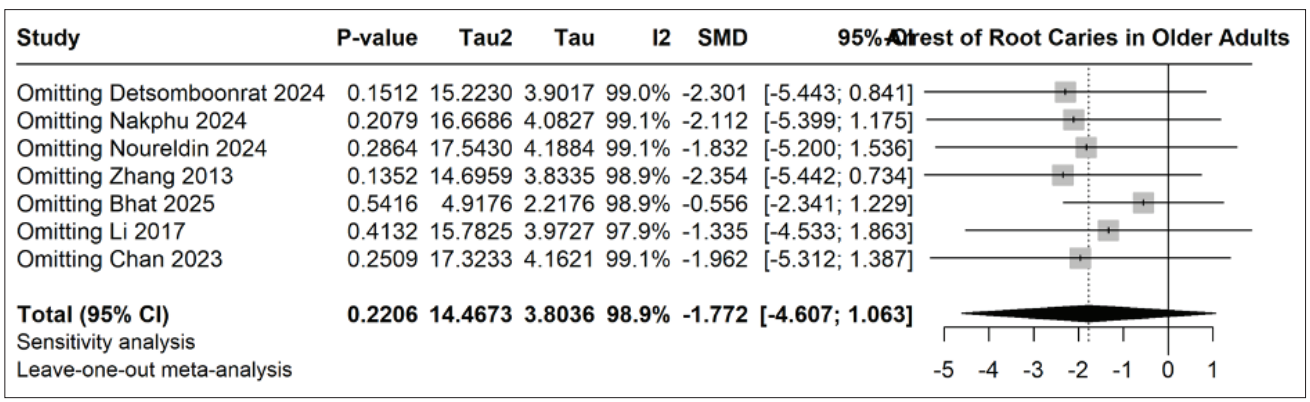

Fig. 3. Forest plot illustrating the sensitivity analysis of arrest of root caries in older adults.

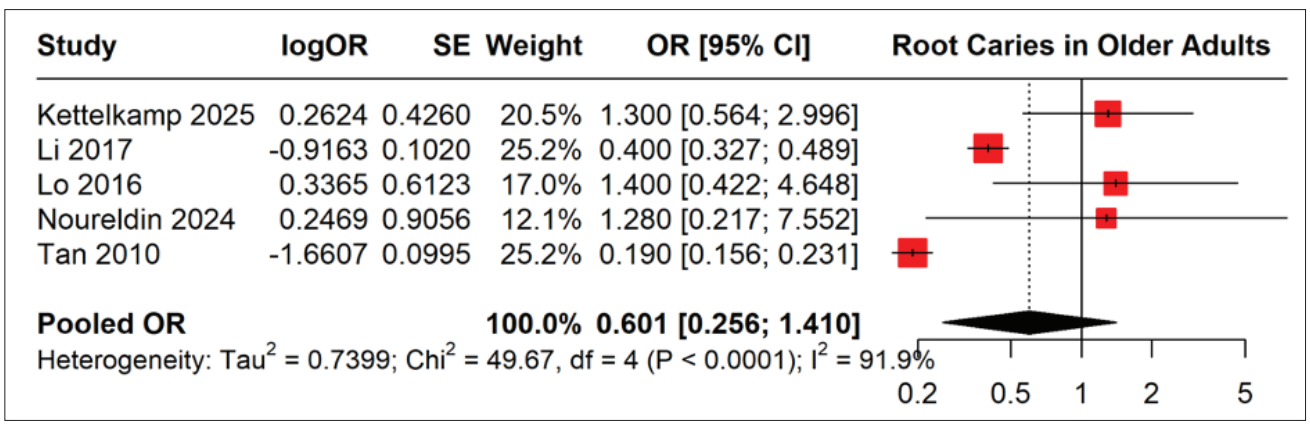

Fig. 4. Forest plot showing the arresting of root caries in older adults based on effect sizes.

significant protective effects. The overall OR, when combined, was 0.60 (95% CI, 0.26–1.41), which shows no statistically significant association of SDF use with caries arrest (Fig. 4). There is considerable heterogeneity among studies (I^2=91.9%; P<0.001) that is suggestive of great diversity in participant characteristics, SDF concentration and frequency, and length of follow-up. Taken together, all these findings suggest that the existing evidence still is inadequate to confirm SDF as a consistently effective intervention to stop root caries progression among older adults. More well-designed, standardized clinical trials are warranted to establish its long-term efficacy and repeatability.

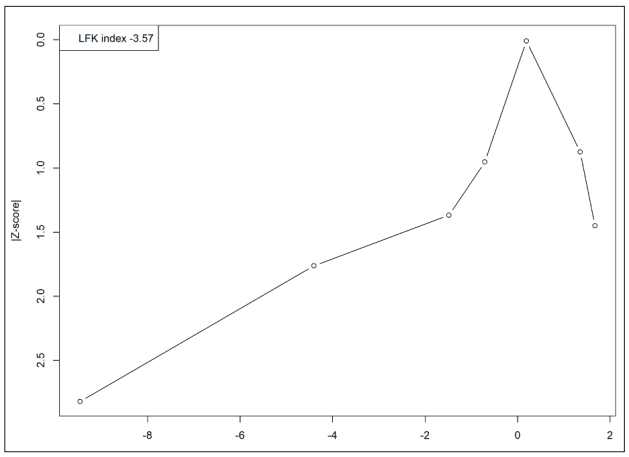

Fig. 4. DOI plot showing the publication of included studies.

Sensitivity analyses that excluded studies rated as having a high risk of bias did not materially alter the direction or magnitude of the pooled effect estimates. The overall conclusions did not change, and no single study was found to disproportionately influence the summary results. These results indicate that the observed lack of a statistically significant association between the use of SDFs and the arrest of root caries was robust to the exclusion of methodologically weaker studies.

Publication bias

There is obvious asymmetry in the Doi plot, with the LFK index at –3.57, indicating major distortion (Fig. 5). The fact that this imbalance is present within the plot might point towards publication bias or small study effects. Several of these estimates are clustering around one side of the plot, which might point towards concerns of selective reporting or differences in study quality. So, care should be taken when interpreting the forest plot.

Evaluation for publication bias using the Doi plot revealed strong asymmetry, where the LFK index was -3.57. This index indicates strong small-study effects. This is important since it can also lead to a reduction in the interpretability of summary estimates. This is because smaller studies tend to produce more extreme estimates.

Results obtained from odds ratio analysis, which were representative of clinically meaningful arrest outcomes, failed to indicate significant association between the application of SDF and the arrest of root caries. Results obtained from SMD analysis were deemed to hold supportive value as they were representative of findings prevalent in grasp of interest.

Heterogeneity and Interpretation

High levels of heterogeneity were evident in both standardized mean differences (I^2=98.9%) and odds ratio-based meta-analyses (I^2=91.9%), representing significant levels of clinical and methodological variability in individual studies. Important variables contributing to heterogeneity levels were: SDF concentration (from low-dose formulation to 38% SDF), treatment regimens (typified by single treatment sessions, annually, and multiple treatment sessions), duration of follow-ups, criteria used to establish a diagnosis of arrested root caries in subjects, as well as population source (institutionalized vs. noninstitutionalized subjects in both institutionalized and noninstitutionalized geriatric populations). Given that very few individual studies provided data for all considered variables in a homogeneous manner, appropriate subgroup analysis/meta-regression analysis were not possible. Hence, individual meta-analysis estimates may reasonably represent averaged treatment effects in highly variable conditions representing broad trends for SDF treatment in geriatric subjects instead of generally accepted measures of treatment effectivity.

Discussion

This systematic review and meta-analysis synthesized current evidence about the effectiveness of SDF in arresting and preventing root caries in older adults. Results indicated no statistically significant benefit of SDF over placebo or alternative interventions in arresting root caries progression, although several individual trials demonstrated favorable trends. These findings contrast with the consistently strong caries-arresting effects reported for SDF in primary teeth and in root caries among mixed-age populations, thereby suggesting that the geriatric context introduces unique biological, behavioral, and methodological challenges that may attenuate treatment efficacy. In the absence of clear benefit demonstrated here, a critical need is emphasized for standardized protocols, longer follow-up, and targeted research focused specifically on older adults at high caries risk.

Previous systematic reviews have shown high arrest rates for SDF in coronal and root caries (33). A systematic review in 2016 showed that treatment with 38% SDF resulted in an overall lesion-arrest rate of about 81% (95% CI 68%-89%) in included studies of children, although the authors noted that most trials were small and heterogeneous (4). Similarly, a review by Seifo et al. (34) on SDF reported that the evidence generally supports its ability to arrest caries, including among adults, but also highlighted considerable variability in review quality, heterogeneity in study designs, and inconsistencies in follow-up

duration. However, the present findings differ in that the pooled standardized mean difference was close to null (SMD=−0.02), with wide confidence intervals and substantial heterogeneity, which suggests that when assessed in a strictly older population and under more rigorous inclusion criteria, the apparent effectiveness of SDF is less certain. These discrepancies illustrate the importance of population-specific clinical evidence in geriatric dentistry, where disease presentation, saliva composition, oral hygiene capability, and comorbidities may influence outcomes.

Unlike in pediatric populations, where SDF is highly effective against dental caries even with annual or biannual application, the failure to demonstrate consistent arrest in older adults may reflect underlying differences in lesion activity and host response. In general, older adults have a higher caries burden, exposed root surfaces related to gingival recession, xerostomia due to polypharmacy, and poorer manual dexterity, complicating caries arrest and prevention (4,6,35). Not only is the mineral content substantially lower and the organic matrix higher in root dentine compared with enamel, but this also makes it more permeable and more susceptible to acid-mediated demineralization. Thus, more frequent SDF application in cases of root caries in older adults, or the use of adjunctive strategies, may be needed to achieve predictable arrest (6,36). These considerations help explain the high degree of between-study variance, I^2=98.9%, revealed by this review, suggesting that future trials will have to adopt stratified analyses and tailored protocols.

The mechanisms of SDF are multifunctional: silver ions exert broad-spectrum antibacterial action, while fluoride favors the deposition of fluorapatite in previously demineralized tissues (37). Ammonia acts as a stabilizer that increases alkalinity, enhances fluoride diffusivity, and inhibits dentin collagen degradation by reducing matrix metalloproteinase activity (38,39). These effects may be less predictable in older adults because biofilms in geriatric populations-particularly among those patients who suffer from xerostomia or reside in long-term care facilities-tend to be more mature, dysbiotic, and enriched with acidogenic and proteolytic microorganisms (40,41). Furthermore, material diffusion may be compromised by sclerotic and mineral-depleted root dentin, which could decrease the depth and homogeneity of SDF action.

Clinical application frequency may be another determinant of success. While many trials have utilized single or annual application protocols, there is evidence to suggest that more frequent reapplication, such as every six months or even quarterly, results in higher arrest rates for root caries lesions in older adults (11,17). The lack of standardization in treatment across included studies may partially account for the variable findings in this review and reinforces a need for consensus-based clinical pathways.

The large heterogeneity (I^2>90%) in the pooled estimate probably reflects very significant differences in study design, sample size, duration of follow-up, diagnostic criteria, and methods of outcome measurement, which have been identified in previous reviews of SDF trials (42,43). The range of included studies varied from small pilot RCTs enrolling less than 50 participants to larger cohorts conducted at the community level; lesion arrest was assessed by using different diagnostic threshold criteria including tactile inspection, radiographic scoring, and ICDAS-based systems. Ekstrand's criteria and the ICDAS-II system were recommended standardised diagnostic frameworks for root caries to allow better comparison across future RCTs (44,45).

Publication bias and small-study effects are clearly detected by Doi plot asymmetry and an LFK index indicating major distortion. This is in line with the general literature on SDF, where small single-site RCTs have often reported particularly positive outcomes. Underreporting of negative or neutral findings may have contributed to an inflated perception of efficacy in earlier reviews.

In previous literature concerning silver diamine fluoride, there have been prominent observations of caries arrests at a high rate, which has been considered for making uniform judgments regarding its efficacy. Nevertheless, many of these studies have possibly overestimated treatment effects, owing to the limitations of studies possessing small sample size and single-site clinical trials, short-term follow-ups, and inadequate accounting for clinical heterogeneity. Conversely, in the current meta-analysis, large amounts of heterogeneity along with pronounced small-study bias, indicated by prominent Doi plot asymmetry, have been observed, providing evidence for overestimation of previously noted favorable effects. Keeping firmly within more restricted venues of evidence exclusively categorizing older adults and applying modern standards of evidence for study methodology, evidence for its efficacy might seem to vary more.

The overall quality of evidence remains limited, with most studies reporting unclear allocation concealment, lack of blinding, and incomplete outcome reporting. The adherence to CONSORT and SPIRIT guidelines is still inconsistent, especially regarding outcome registration and prospective protocol availability. In addition, there was limited control for confounders in non-randomized studies, such as oral hygiene, salivary function, dietary habits, and socioeconomic status-all known to impact root caries risk in older adults (6,46).

While SDF is widely adopted in pediatric and special care dentistry due to its affordability, simplicity, and non-invasive application, the translation of the same to the geriatric population calls for re-evaluation. Current evidence suggests that SDF may arrest early root caries in some older adults, although this action is not consistent and might be influenced by disease activity, adjunctive care, and application frequency. This review suggests that SDF should not be used alone for high-risk older adults but integrated into a comprehensive prevention protocol with remineralizing agents, chlorhexidine therapy, salivary stimulants, oral hygiene support, and dietary counselling. Prevention models such as the CAMBRA framework or the ICCMS system, when tailor-made applications are provided with SDF, may improve the outcomes in this population (47).

Patient acceptance is a relevant practical consideration. The irreversible black discoloration that results from SDF has been reported to impact both patient and caregiver attitudes, but it is less critical for root-surface lesions than for anterior enamel lesions. Recent qualitative studies indicate that, for older adults, retention of teeth tends to take precedence over esthetics, especially in settings with limited access to restorative services (48,49). Shared decision-making could be applied further to better align clinical strategies with patient values.

Future studies are needed to address these current uncertainties. Such studies would, in the case of SDF, include rigorously designed multi-center RCTs that use standardized diagnostic criteria, fixed SDF concentrations (usually 38%), pre-determined application intervals, and at least 24 months of follow-up (11). Stratified analyses according to xerostomia, dementia, frailty status, and polypharmacy may elucidate which subsets of patients will benefit most from SDF. There is increasing interest in adjunctive approaches, combining SDF with potassium iodide, fluoride varnishes, or remineralizing agents like CPP-ACP, as initial results from these combinations have demonstrated possible improvements in clinical efficacy and/or diminished discoloration of SDF (43).

There is also a need for real-world implementation research in residential care homes and community-based geriatric programs. Most clinical trials exclude institutionalized or medically compromised elders, although these are the populations with the greatest unmet caries treatment needs. Finally, cost-effectiveness analyses and qualitative studies assessing caregiver and patient perception of SDF could support policy recommendations and assist in integrating SDF into geriatric oral health programs at scale.

The high level of heterogeneity found in the current meta-analysis is indicative of the complexity involved in assessing the efficacy of SDF in the management of root caries among senior individuals. While pediatric subjects tend to be relatively more homogeneous with regards to susceptibility to diseases, ability to perform oral hygiene measures, co-morbidity level, salivary capability, and accessibility to dental treatments, the same is not true for elderly patients.

Therefore, when interpreting the pooled results presented in this review, one should not see them as suggesting a similar lack of effectiveness but rather as a confirmation that the effectiveness of SDF among seniors is highly dependent on context. Such results are well in line with calls for future multicenter trials with similar protocols and preset subgroup analyses to determine which patients would be most likely to derive benefit from SDF treatment. The observed level of heterogeneity also serves to point out that the results of the pooled analysis of effects reflect a degree of heterogeneity in definitions of a clinical context and should not in any case be considered as a definition of a treatment effect. The degree of heterogeneity observed here is considered to be very high.

Notably, however, the lack of statistically significant pooled estimates in the above meta-analysis should not be interpreted as indicating the ineffectiveness of silver diamine fluoride in the management of root caries in older individuals. This is largely because the lack of statistical significance is largely driven by high levels of discrepancies between studies, along with various levels of intervention and outcome measures.

The strengths of this review include adherence to the PRISMA 2020 criteria and PROSPERO registration, thus ensuring that the review methodology is transparent and reproducible. Comprehensive multi-database search, inclusion of both RCTs and observational studies, and the application of modern metrics of publication bias, like the LFK index, provide greater confidence in the findings. However, heterogeneity of included studies prohibited subgroup analyses and reduces comparability due to a lack of consistent reporting. Further, access to unpublished data was not available for evaluation. Most studies used surrogate measures of cariological change without microbiological or salivary biomarkers, reducing mechanistic interpretation of the results. Lack of access to individual participant data also limits the ability to conduct meta-regression or assess patient-level modifiers. Importantly, sensitivity analyses excluding studies at high risk of bias yielded consistent results, supporting the robustness of the overall findings. Nevertheless, the predominance of moderate-quality evidence underscores the need for well-designed randomized trials with rigorous bias control.

The presence of extreme asymmetry in the Doi plot suggests the presence of strong small study effects (LFK index=-3.57). This is an issue of possible publication bias.

This could be the cause of exaggerated or imprecisely estimated effect measures and hence the need to exercise caution in the interpretation of combined estimates in the presence of notable heterogeneity and differing quality of studies.

In the absence of a quantitative assessment for grading the certainties of the evidence, the net overall level of confidence in the primary outcome results in this specific review would best be described as low to moderate in the face of a high degree of heterogeneity among the studies, the presence of small study effects, as well as divergent study designs, outcome criteria, and treatment regimens. Despite the observation that some studies showed a positive outcome associated with SDF, the data were inconsistent in the study findings, which tended to arise from less methodologically consistent or smaller-scale trial studies. In the absence of a specific GRADE analysis, it can qualitatively be assessed now that the certainty of evidence for all primary outcomes might be low to very low. This follows because of large heterogeneity across studies, lack of quality of included studies consisting of several lower-quality studies, evidence of small study effects, and possible publication bias.

However, by and large, the degree of evidence for the primary outcomes is impaired by considerable clinical and methodological heterogeneity, risks of bias across studies included, and evidence of publication bias and small study effects.

Clinically, it may be stated that while odds ratios calculated using dichotomous measures of caries arrest are more relevant with respect to treatment choice in older patients than standardized mean differences because of their relevance and interpretability with respect to clinical practice, it is these latter values that are more precise measures of the heterogeneous nature of continuous measures of clinical effectiveness. From a clinical perspective, a value close to zero for the standardized mean difference suggests there is little or no detectable difference between intervention and control groups on caries arrest outcomes when results are combined from different studies. For this particular systematic review, a value for the estimate of SMD tending to zero implies there is little evidence about a detectable difference is there between silver diamine fluoride and controls regarding overall treatment outcomes when combined from different populations which tend to be more heterogeneous regarding treatment protocols and research designs to the same extent. Notably, this particular interpretation should be placed correctly and should not be considered conclusive about ineffectiveness under any circumstances.

Conclusion

This systematic review and meta-analysis suggests that the effectiveness of SDF for arresting and preventing RC in older adults depends upon the context in which it is applied. Although there was no evidence for a statistically significant benefit, the high levels of heterogeneity obvious in the studies conducted do not allow any conclusive interpretations. Hence, SDF should be considered as a sensitive procedure that cannot be considered as universally effective. Overall, these findings offer a much-needed balancing effect for the assumed universal effectiveness of SDF in the population of older adults and reflect the intense need for properly structured studies that can effectively guide evidence-based practice in geriatric dental care.

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ORIGINAL ARTICLE

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A Scientometric Evaluation of Türkiye's Research Productivity in High-Impact Endodontic Journals: A 41-Year Bibliometric Analysis

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Purpose: This study aims to examine scholarly communication patterns in high-impact endodontic journals through a bibliometric analysis of Türkiye-affiliated publications in the Journal of Endodontics, International Endodontic Journal, and Australian Endodontic Journal.

Methods: A total of 753 Web of Science–indexed articles published between 1983 and 2024 were analyzed using Bibliometrix in R with supplementary statistical analyses. Publications were evaluated in terms of document types, subject categories, citation performance, authorship and institutional productivity, multidisciplinary structures, and national and international collaboration patterns.

Results: Root canal preparation and irrigation–disinfection were the most frequently investigated topics, and laboratory-based studies predominated. The highest citation impact was observed in the Journal of Endodontics. Hacettepe University was the most productive institution, and Hakan Arslan the most prolific author. International collaborations were most frequently established with the United States.

Conclusion: This bibliometric analysis provides an overview of Türkiye-affiliated research productivity and trends in high-impact endodontic journals. Building on these findings, fostering interdisciplinary collaboration and expanding international partnerships may further strengthen scientific visibility and impact. Research performance should be evaluated not only by the number of publications but also by citation metrics and the h-index to provide a more accurate and balanced assessment of academic impact.

Keywords: Bibliometric analysis; citation analysis; collaboration networks; endodontics; research evaluation.

Introduction

Bibliometrics is an important method for the quantitative evaluation of scientific publications, serving as a key tool for the systematic examination of academic literature. Using statistical and mathematical techniques, this approach helps identify research output, trends, and levels of impact across different scientific fields. Bibliometric studies allow researchers to explore trends, collaboration networks, and patterns of scientific productivity within their disciplines. This method also provides a comprehensive overview of

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the academic literature, making it possible to identify gaps in specific areas and suggest ways to address them (1,2).

There are many databases available for collecting data used in bibliometric analyses. The most used and internationally recognized databases include WoS, Scopus, and Google Scholar. For evaluating individual researchers, the most basic bibliometric indicators are the number of publications and citations. With the growth of digital resources, new indicators such as the h-index have been developed, forming the basis of more advanced bibliometric measures (3). To assess the academic influence of journals, the two-year impact factor is one of the most frequently used indicators (4). These parameters are increasingly important in evaluating academic productivity, faculty promotion processes, and research funding applications (5).

Citation analysis, one of the most common methods in bibliometric research, evaluates the scientific and clinical importance of a publication by examining how often it is cited by other researchers. Although citation count alone does not fully represent the scientific or clinical value of a study, it provides an objective reference point for researchers and clinicians to follow technological advances, assess current trends, and support evidence-based decision-making (1). Clarivate is a tool that systematically searches and indexes thousands of scientific journals to create a comprehensive database (6). The WoS search platform within Clarivate includes several citation indexes, such as the Science Citation Index (SCI), Social Sciences Citation Index (SSCI), and Arts & Humanities Citation Index (A&HCI) (7). The Science Citation Index Expanded (SCIE), previously known as the SCI, was developed under the leadership of Eugene Garfield. WoS covers more than 250 academic subjects and is well-known all over the world. Many top academic institutions support it (8).

Since the introduction of SCI in 1961, the journal impact factor has become an important criterion for evaluating academic journals (9). The impact factor is calculated by dividing the total number of citations received in a given year for articles published in the previous two years by the total number of articles published in the same period (10). It remains one of the most widely used indicators for assessing a journal's academic influence (4).

In the WoS database, the Journal of Endodontics (JOE), International Endodontic Journal (IEJ) and Australian Endodontic Journal (AEJ) are three highly regarded endodontic journals with strong impact factors. By publishing scientific work from different regions, these journals contribute to the global dissemination of knowledge produced in various countries (11).

JOE is the official journal of the American Association of Endodontists and has been published monthly since 1975. According to the Journal Citation Reports (12), it ranks 22nd among 162 dentistry journals and is considered a leading publication for dental professionals. Its 2024 impact factor is 3.6. IEJ is a peer-reviewed journal in the field of endodontics and serves as the official publication of both the British Endodontic Society and the European Society of Endodontology. It was originally published between 1967 and 1980 under the title Journal of the British Endodontic Society and was relaunched as IEJ in 1980. In 2024, its impact factor was 7.1, ranking 3rd among all dentistry journals. AEJ is the official journal of the Australian Society of Endodontology and has been indexed in the SCI-Expanded since 1998. It is published three times per year. The journal's 2024 impact factor is 1.5, placing it 105th among dentistry journals.

The aim of this study was to examine scholarly communication patterns in high-impact endodontic journals by conducting a bibliometric analysis of Türkiye-affiliated publications in the Journal of Endodontics, International Endodontic Journal, and Australian Endodontic Journal. Accordingly, the null hypothesis assumes no statistically significant differences among these journals in terms of citation performance.

Materials and Methods

Data source and search strategy

All publications from the three journals were retrieved from the WoS database, specifically from sources indexed within the SCI-Expanded.

An electronic search was conducted in the WoS database in January 2024. The search strategy was defined using the criteria "Journal Name" and "Address," and publications affiliated with Türkiye were filtered accordingly. All articles published from the year of the first Türkiye-originated publication in each journal (JOE, 1983; IEJ, 1985; AEJ, 2008) up to 2024 were included. No time restrictions were applied.

Inclusion and exclusion criteria

Only original research articles, case series, case reports, and review articles published with a Turkish affiliation were included in the study. Editorial materials, letters to the editor, corrections, and proceeding papers were excluded (Fig. 1). Accordingly, a total of 753 articles were included in the analysis: 398 from JOE, 233 from IEJ, and 122 from AEJ.

Data extraction

The following information was obtained and evaluated from the included articles: Type of article, research topic,

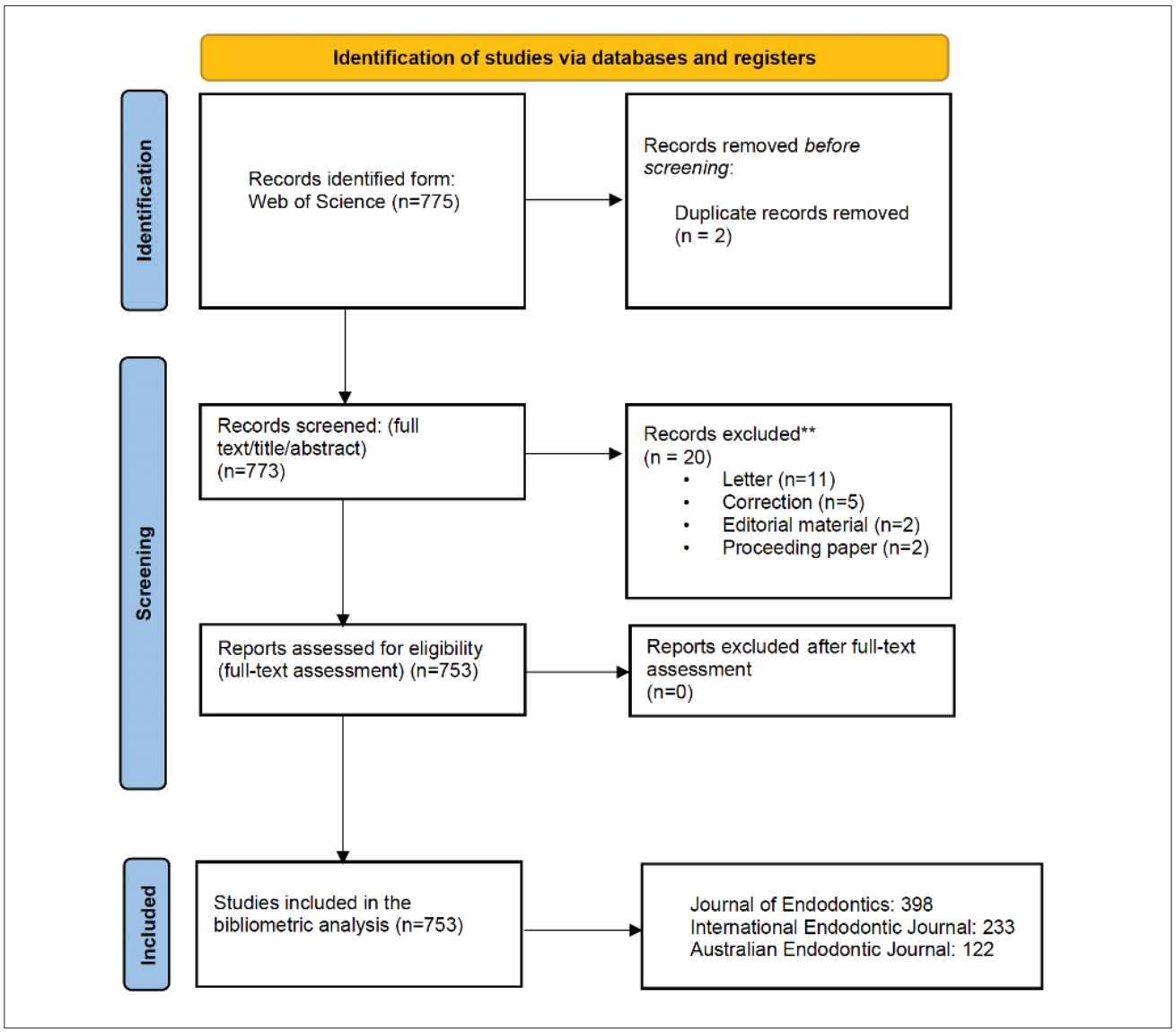

Fig. 1. Flow diagram of literature search and selection criteria (adapted from the PRISMA 2020 flowchart).

number of citations, number of authors, affiliated institution, presence of multidisciplinary collaboration, presence of national or international, cooperation, keywords.

The publications were classified into five main categories: Clinical studies, laboratory studies, animal studies, case reports/series, and review/systematic review–meta-analysis articles. The research topics were determined based on the abstracts and keywords of each study. Institutional and multidisciplinary characteristics were categorized according to the authors' affiliations and research fields. For the collaboration analysis, national and international cooperation was identified based on the institutional affiliations of all authors.

Data analysis

Publications retrieved from the WoS database were exported in BibTeX format and imported into the analysis system. Bibliometric analyses were conducted using the Bibliometrix package and the Biblioshiny interface, both compatible with the R programming language and known for their advanced visualization capabilities. All analyses were performed using RStudio Version 4.4.2

In addition to the software-based analysis, all articles were manually reviewed to extract supplementary information not captured by the program. In addition to the bibliometric data obtained through the Bibliometrix software, all articles were manually reviewed to evaluate variables

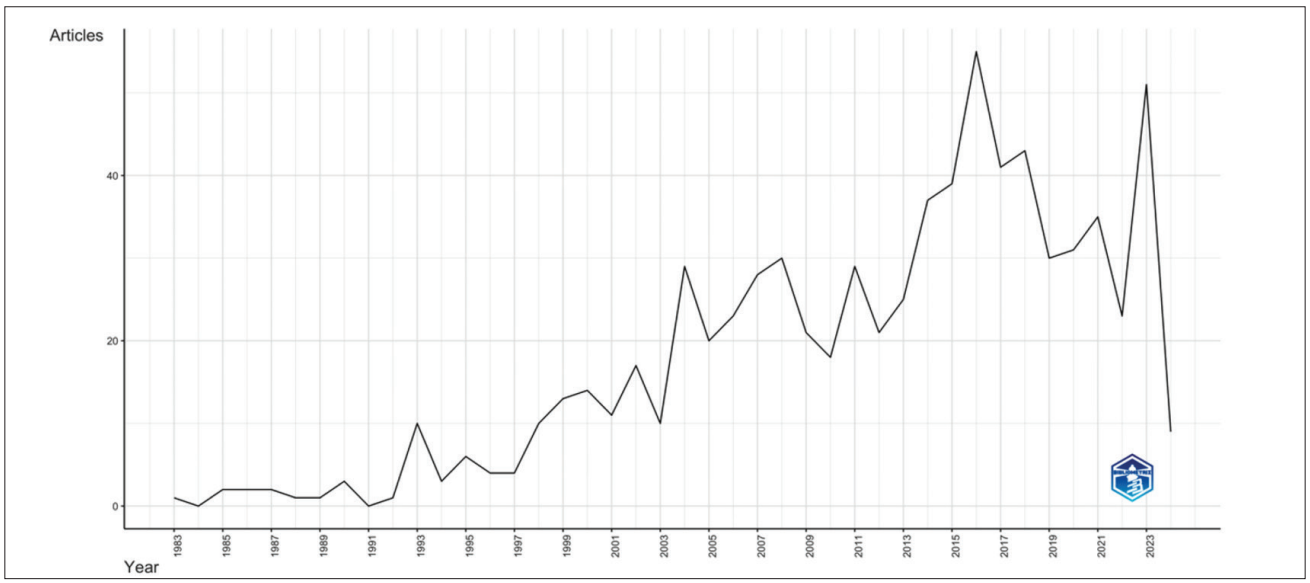

Fig. 2. Annual distribution of Türkiye-affiliated publications in JOE, IEJ and AEJ (JOE: Journal of Endodontics, IEJ: International Endodontic Journal, AEJ: Australian Endodontic Journal)

that could not be directly extracted by the program. In this context, the research topics of the articles, publication types (e.g., original research articles, reviews, etc.), study typologies (e.g., clinical studies, laboratory studies, animal studies, etc.), number of authors, and characteristics of multidisciplinary collaboration as well as national and international collaboration were determined manually. Research topics were classified based on the titles, abstracts, and keywords of the articles. Publication type and study typology were assessed according to their methodological content. Multidisciplinary collaboration was determined by examining the institutional affiliations and areas of expertise of the authors, whereas the presence of national or international collaboration was identified based on the countries of the authors' institutions. This manual evaluation process aimed to systematically obtain data that could not be automatically generated by the Bibliometrix software and thereby enhanced the comprehensiveness of the study.

Statistical analyses were carried out using SPSS Version 22 (IBM SPSS Statistics, Armonk, NY, USA). The normality of data distribution was tested using the Kolmogorov–Smirnov test. Descriptive statistics were expressed as median (minimum–maximum) values. The Kruskal–Wallis test, Mann–Whitney U test, and Bonferroni correction were applied for group comparisons. A p-value of <0.05 was considered statistically significant.

Results

The annual distribution of the included articles is presented in Figure 2. It was observed that the number of publications has steadily increased since 2004, reaching its peak in 2016 with a total of 56 articles.

Among the 753 articles included in the study, the most frequently investigated topics were root canal preparation (n=134) and irrigation–disinfection (n=131). A total of 378 studies did not involve a multidisciplinary approach, while 375 studies incorporated a multidisciplinary design. Most studies (408) were conducted without institutional or country-level collaboration. These were followed by national collaborations (217 studies), international collaborations (98 studies), and combined national–international collaborations (30 studies).

Regarding authorship, the number of authors per article

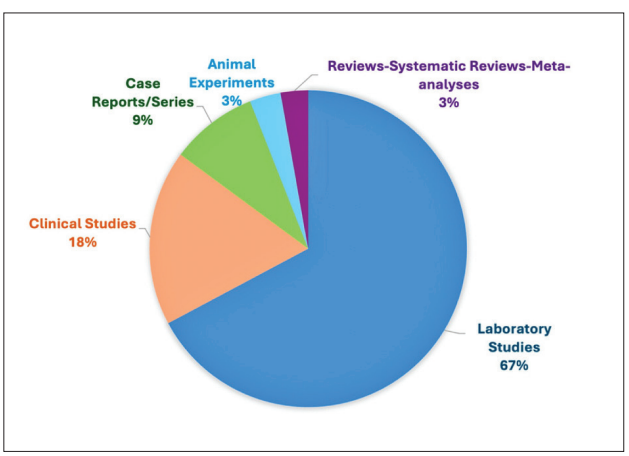

Fig. 3. Research typology of Türkiye-affiliated publications .

Table 1. Authors, publication year, citation counts, article titles, and journals of the 50 most cited articles

Authors	Years	Total Citations	Article Titles	Journal
Sert S & Bayırlı GS	2004	357	Evaluation of the root canal configurations of the mandibular and maxillary permanent teeth by gender in the Turkish population	J0E
Calt S & Serper A	2002	300	Time-dependent effects of EDTA on dentin structures	J0E
Calıskan MK et al.	1995	222	Root-canal morphology of human permanent teeth in a turkish population	J0E
Sen BH et al.	1995	185	The smear layer - a phenomenon in root-canal therapy	IEJ
Orhan K et al.	2020	179	Evaluation of artificial intelligence for detecting periapical pathosis on cone-beam computed tomography scans	IEJ
Eskitascioglu G et al.	2002	158	Evaluation of two post core systems using two different methods (frac-ture strength test and a finite elemental stress analysis)	J0E
Cehreli ZC et al.	2011	143	Regenerative endodontic treatment (revascularization) of immature necrotic molars medicated with calcium hydroxide: a case series	J0E
Capar ID et al.	2014	141	Comparative study of different novel nickel-titanium rotary systems for root canal preparation in severely curved root canals	J0E
Nagas E et al.	2012	139	Dentin moisture conditions affect the adhesion of root canal sealers	J0E
Tanalp J & Gungor T	2014	139	Apical extrusion of debris: a literature review of an inherent occurrence during root canal treatment	IEJ
Segura-Egea JJ et al.	2018	129	European Society of Endodontology position statement: the use of anti-biotics in endodontics	IEJ
Yoldas O et al.	2012	129	Dentinal microcrack formation during root canal preparations by different NiTi rotary instruments and the Self-Adjusting File	J0E
Bezgin T et al.	2015	127	Efficacy of platelet-rich plasma as a scaffold in regenerative endodontic treatment	J0E
Guneser MB et al.	2013	125	Effect of various endodontic irrigants on the push-out bond strength of biodentine and conventional root perforation repair materials	J0E
Ercan ER et al.	2004	125	Antibacterial activity of 2% chlorhexidine gluconate and 5.25% sodium hypochlorite in infected root canal: In vivo study	J0E
Erdemir A et al.	2004	125	Effect of medications for root canal treatment on bonding to root canal dentin	J0E
Tinaz AC et al.	2005	121	The effect of disruption of apical constriction on periapical extrusion	J0E
Yaltirik M et al.	2004	119	Reactions of connective tissue to mineral trioxide aggregate and amalgam	J0E
Dogan H & Calt S	2001	119	Effects of chelating agents and sodium hypochlorite on mineral content of root dentin	J0E
Segura-Egea JJ et al.	2017	118	Antibiotics in Endodontics: a review	IEJ
Ari H et al.	2003	118	Effects of NaOCl on bond strengths of resin cements to root canal dentin	J0E
Ulusoy AT et al.	2019	115	Evaluation of blood clot, platelet-rich plasma, platelet-rich fibrin, and platelet pellet as scaffolds in regenerative endodontic treatment: a pro-spective randomized trial	J0E
Oncag O et al.	2003	114	Comparison of antibacterial and toxic effects of various root canal irri-gants	IEJ
Calt S & Serper A	1999	110	Dentinal tubule penetration of root canal sealers after root canal dressing with calcium hydroxide	J0E
Sert S et al.	2004	109	Investigation of the root canal configurations of mandibular permanent teeth in the Turkish population	IEJ
Eldeniz AU et al.	2007	107	Cytotoxicity of new resin-, calcium hydroxide- and silicone-based root canal sealers on fibroblasts derived from human gingiva and L929 cell lines	IEJ
Kocak S et al.	2013	104	Apical extrusion of debris using Self-Adjusting File, Reciprocating Single-file, and 2 rotary instrumentation systems	J0E
Ari H et al.	2004	104	Evaluation of the effect of endodontic irrigation solutions on the micro-hardness and the roughness of root canal dentin	J0E
Ozer SY	2011	99	Detection of vertical root fractures by using cone beam computed tomography with variable voxel sizes in an in vitro model	J0E
Azim AA et al.	2016	97	Efficacy of 4 irrigation protocols in killing bacteria colonized in dentinal tubules examined by a novel confocal laser scanning microscope analysis	J0E
Hakkı SS et al.	2009	97	Effects of Mineral Trioxide Aggregate on cell survival, gene expression	J0E

			associated with mineralized tissues, and biomineralization of cemento-blasts	
Sonmez D et al.	2008	97	A comparison of four pulpotomy techniques in primary molars: A long-term follow-up	JOE
Keskin C et al.	2017	96	Cyclic fatigue resistance of Reciproc Blue, Reciproc, and WaveOne Gold reciprocating instruments	JOE
Ungor M et al.	2006	92	Push-out bond strengths: the Epiphany-Resilon endodontic obturation system compared with different pairings of Epiphany, Resilon, AH Plus and gutta-percha	IEJ
Gorduysus M et al.	2001	92	Operating microscope improves negotiation of second mesiobuccal canals in maxillary molars	JOE
Tuna D & Olmez A	2008	90	Clinical long-term evaluation of MTA as a direct pulp capping material in primary teeth	IEJ
Keles A et al.	2014	88	Micro-CT evaluation of root filling quality in oval-shaped canals	IEJ
Kayahan MB et al.	2009	87	Effect of acid-etching procedure on selected physical properties of mineral trioxide aggregate	IEJ
Kayaoglu G et al.	2005	87	Short-term antibacterial activity of root canal sealers to-wards Enterococcus faecalis	IEJ
Oksan T et al.	1993	87	The penetratıon of root-canal sealers ınto dentınal tubules - a scannisng electron-mıcroscopıc study	IEJ
Eldeniz AU et al.	2006	83	Antibacterial effect of selected root-end filling materials	JOE
Belli S et al.	2006	83	Reinforcement effect of polyethylene fibre in root-filled teeth: comparison of two restoration techniques	IEJ
Belli S et al.	2005	83	The effect of fibre insertion on fracture resistance of root filled molar teeth with MOD preparations restored with composite	IEJ
Kartal N et al.	1998	82	Root canal morphology of maxillary premolars	JOE
Gundogar M & Ozyurek T	2017	81	Cyclic fatigue resistance of OneShape, HyFlex EDM, WaveOne Gold, and Reciproc Blue nickel-titanium instruments	JOE
Sagsen B et al.	2011	81	Push-out bond strength of two new calcium silicate-based endodontic sealers to root canal dentine	IEJ
Ozer SY	2010	80	Detection of vertical root fractures of different thicknesses in endodontically enlarged teeth by cone beam computed tomography versus digital radiography	JOE
Tasdemir T et al.	2008	80	Efficacy of three rotary NiTi instruments in removing gutta-percha from root canals	IEJ
Calt S & Serper A	2000	79	Smear layer removal by EGTA	JOE
Ozyurek T et al.	2018	78	The effects of endodontic access cavity preparation design on the fracture strength of endodontically treated teeth: traditional versus conservative preparation	JOE

JOE: Journal of Endodontics, IEJ: International Endodontic Journal, AEJ: Australian Endodontic Journal.

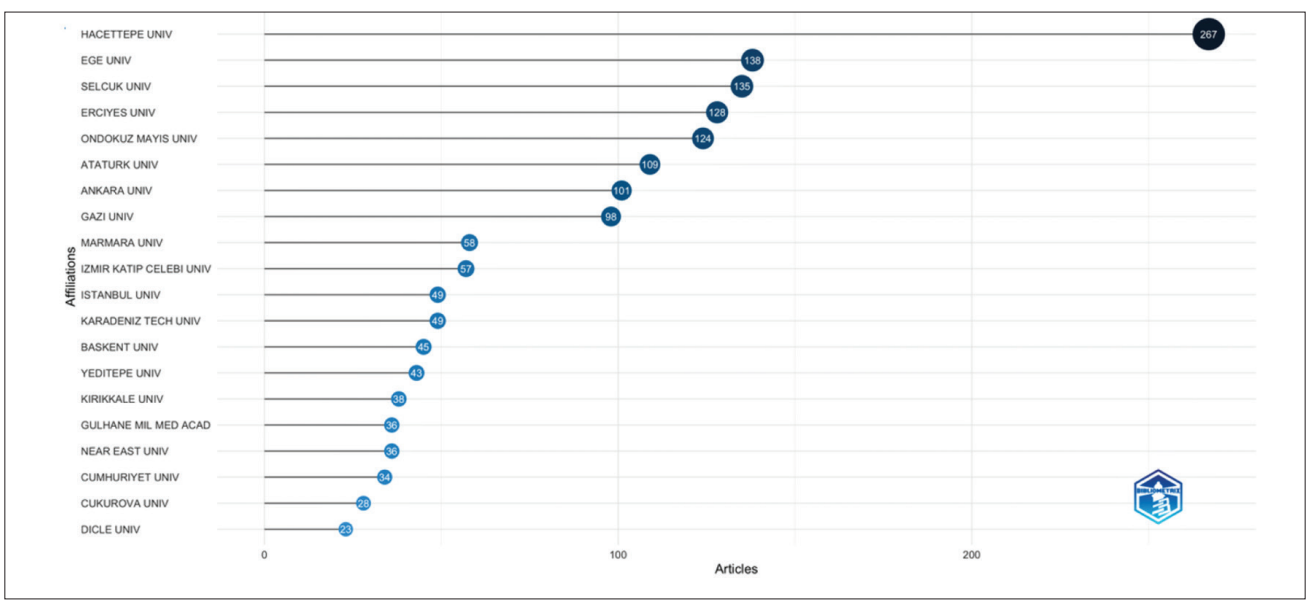

Fig. 4. Publication performance of the top 20 academic institutions producing the highest number of scientific articles.

ranged from 1 to 19, with a median of 4 authors. The majority of studies (506) were laboratory-based. In addition, 135 were clinical studies, 67 were case reports/series, 24 were animal studies, and 21 were systematic reviews or meta-analyses (Fig. 3).

The median number of citations for the 753 articles was 21, with a range of 0–357. Statistical analyses showed a significant difference in how often papers were cited between IEJ and AEJ (P<0.001) and between JOE and AEJ (P<0.001), but no statistically significant difference was seen between IEJ and JOE (P>0.05). Among the most cited publications, the study by Semih Sert and Gündüz S. Bayırlı, published in JOE in 2004, received the highest number of citations with 357 (13). This was followed by the research of Semra Calt and Ahmet Serper, published in the same journal in 2002, which received 300 citations (14). Additionally, the studies by Çalışkan et al. (15), published in JOE in 1995, and Sen et al. (16), published in IEJ in 1995, received 222 and 185 citations, respectively. The full citation details of the 50 most cited articles are presented in Table 1.

The distribution of the reviewed articles by institutions or universities is presented in Figure 4. In the graph, universities are shown on the vertical axis, while the number of published articles is displayed on the horizontal axis. According to these data, Hacettepe University ranks first with 267 articles, followed by Ege University (138), Selçuk University (135), Erciyes University (128), and Ondokuz Mayıs University (124).

The structural analysis and relationship patterns of inter-institutional academic collaborations are visualized in Figure 5. In the network map, the size of the nodes is proportional to the intensity of collaboration for each institution. The analysis revealed that Hacettepe University occupies a central position in the network with the highest number of collaborative connections. Additionally, a strong collaborative triangle was observed among İzmir Kâtip Çelebi University, Atatürk University, and Erciyes University.

The frequency of keyword usage and their interrelationships are shown in Figures 6 and 7. The most frequently used keyword was endodontics (n=56), followed by retreatment (n=41), calcium hydroxide (n=38), root canal (n=31), mineral trioxide aggregate (n=27), and fracture resistance (n=25).

As shown in Figure 8, core terms such as endodontics, retreatment, root canal, calcium hydroxide, and mineral trioxide aggregate have been used frequently and consistently over the years. The term smear layer has been used

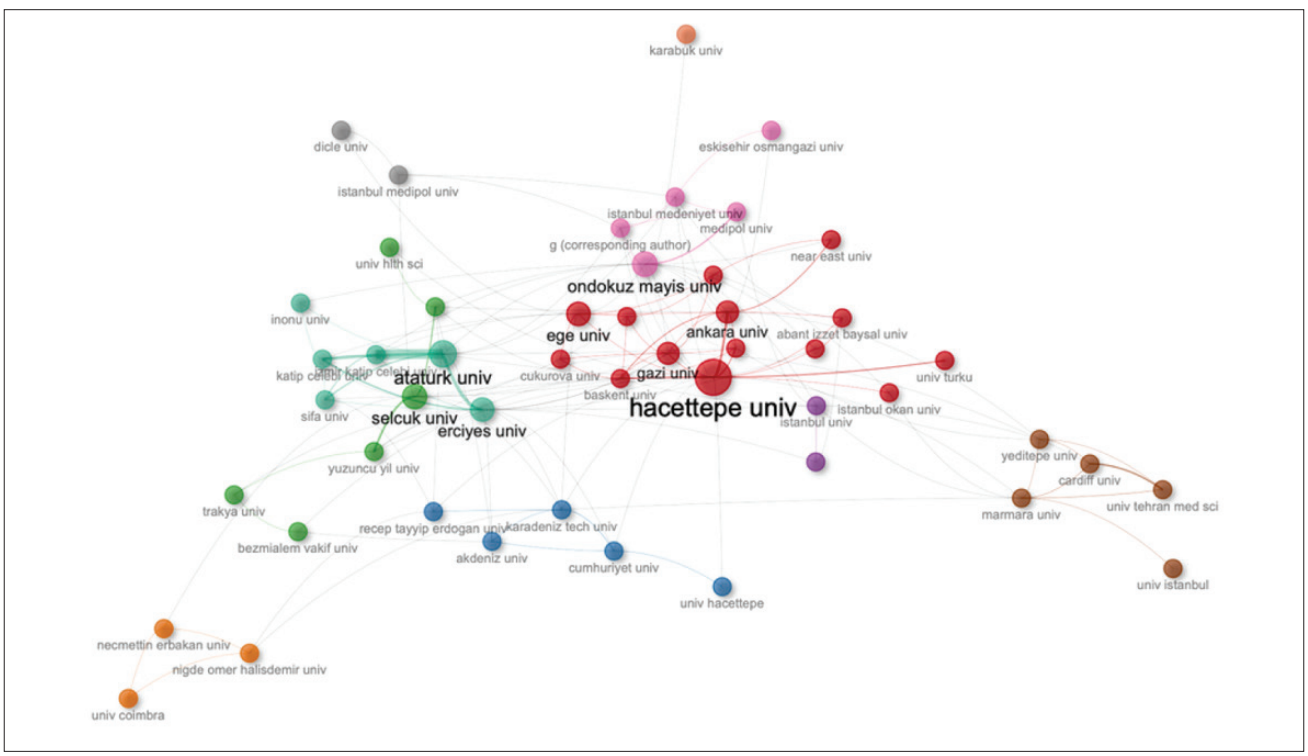

Fig. 5. Inter-institutional collaboration network among universities.

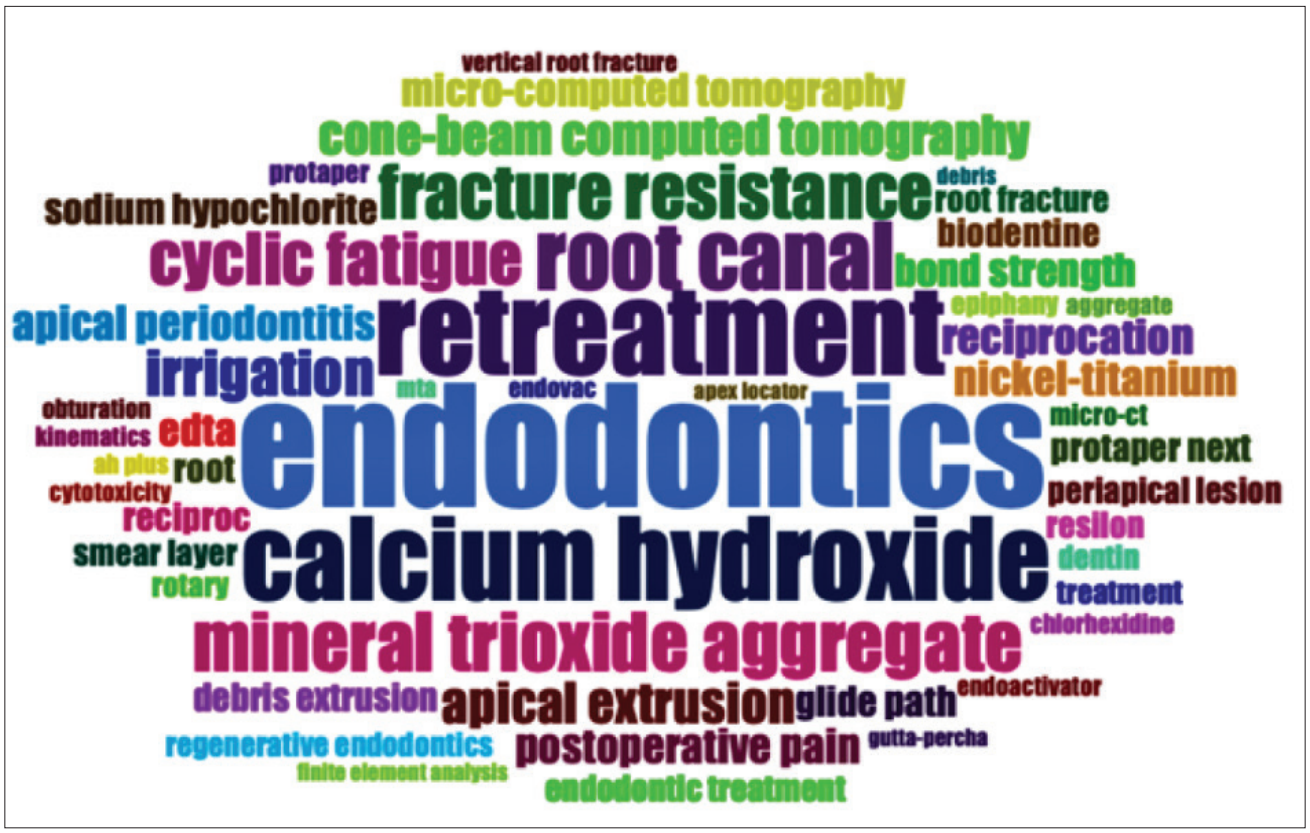

Fig. 6. Most frequently used keywords.

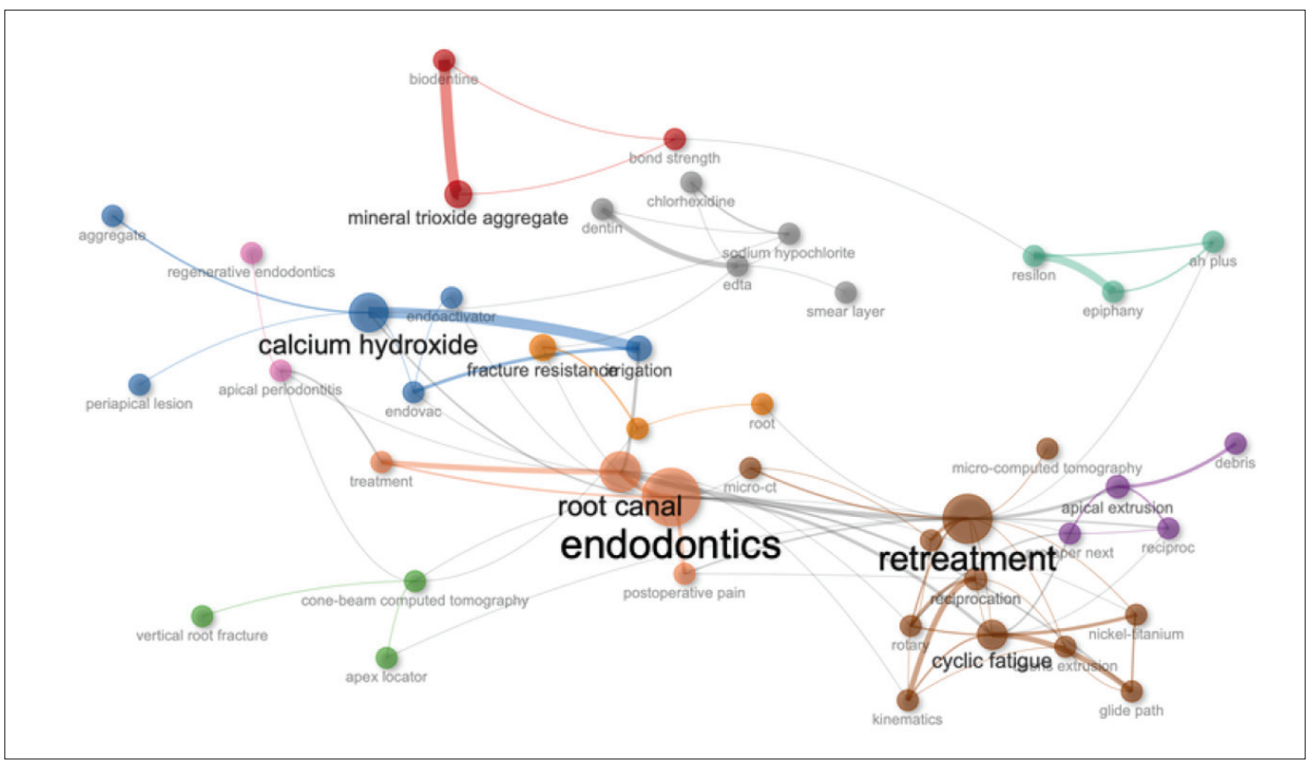

Fig. 7. Network map of the most frequently used keywords.

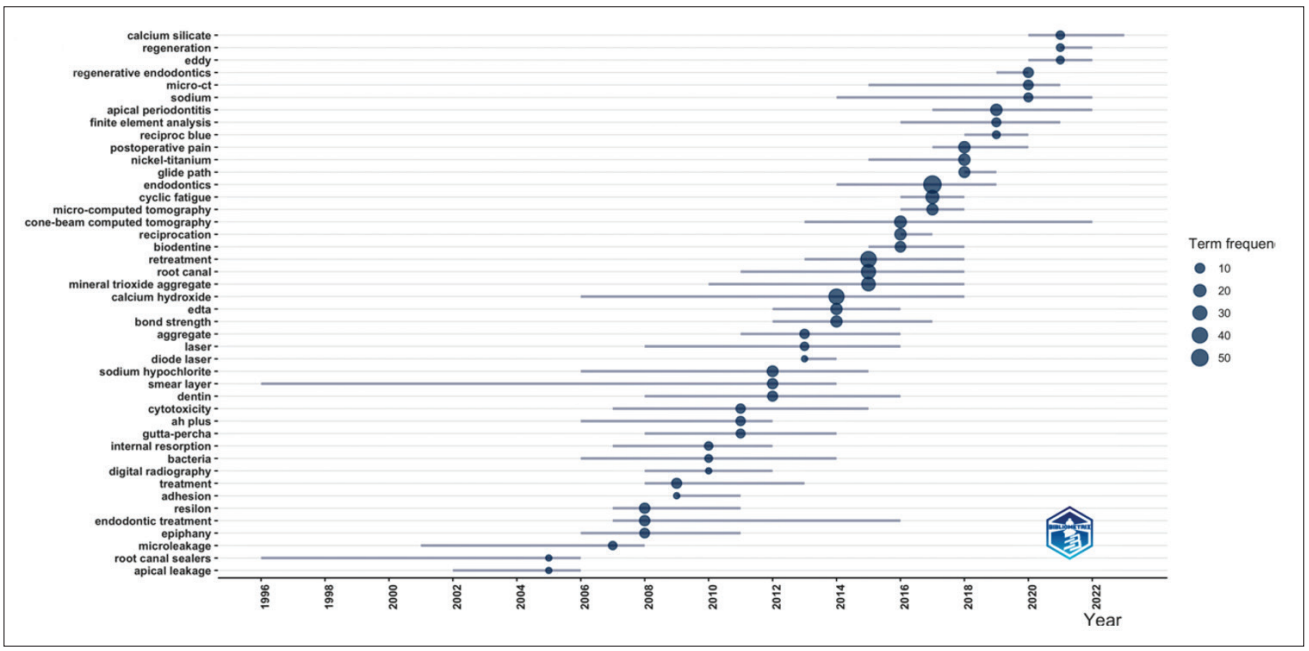

Fig. 8. Trend topics in publications, their annual distribution, and frequency of use.

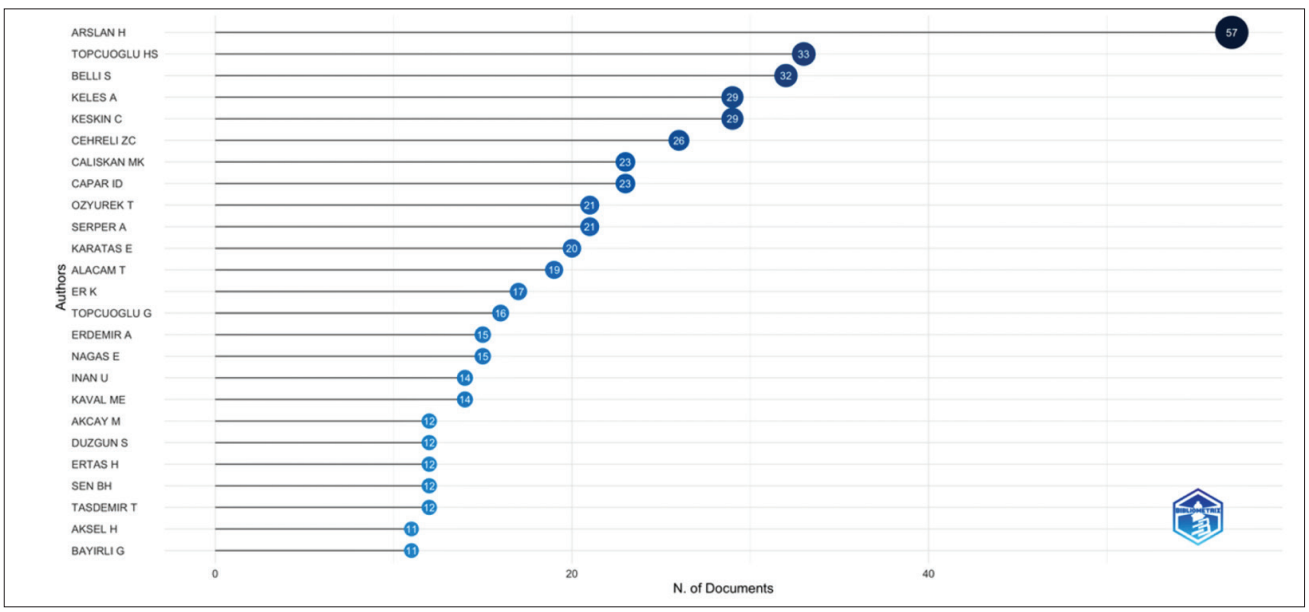

Fig. 9. Ranking of the 25 most productive authors.

in academic literature since the late 1990s, and it was used more in the 2000s. However, no significant increase was observed in recent years (2015 onward). Terms such as regeneration, calcium silicate, EDDY, micro-CT, and finite element analysis have been increasingly used, particularly after 2015.

Among the researchers included in this study, the most prolific author was Hakan Arslan, with 57 publications. Other authors contributing a significant number of articles include Hüseyin Sinan Topcuoglu (33 articles), Sema Belli (32 articles), Ali Keles (29 articles) and Cangül Keskin (29 articles). Data on the total number of articles and h-index of the authors across the three journals are presented in Figures 9 and 10.

When examining the total citation counts of the authors, Hakan Arslan stands out as the most cited researcher with 1731 citations. He is followed by Sema Belli (1408), Ahmet Serper (1035), İsmail Davut Capar (959), and Taha Özyürek (835).

Figure 11 visualizes the scientific productivity and annual citation counts of authors over time. The size of the circles represents the number of articles published in a given year, while the color intensity indicates the number of citations received that year. The graph covers a 41-year period from 1983 to 2024. The first Türkiye-affiliated publication was an in vitro study conducted by Tayfun Alacam and Tamer Yılmaz, published in 1983 in the JOE (17).* As shown, overall academic output has generally increased since the early 2000s. Authors such as Hakan Arslan, Hüseyin Sinan Topcuoglu, Ali Keles, and İsmail Davut Capar demonstrated particularly high productivity in certain years. On the other hand, Tayfun Alacam and Mehmet Kemal

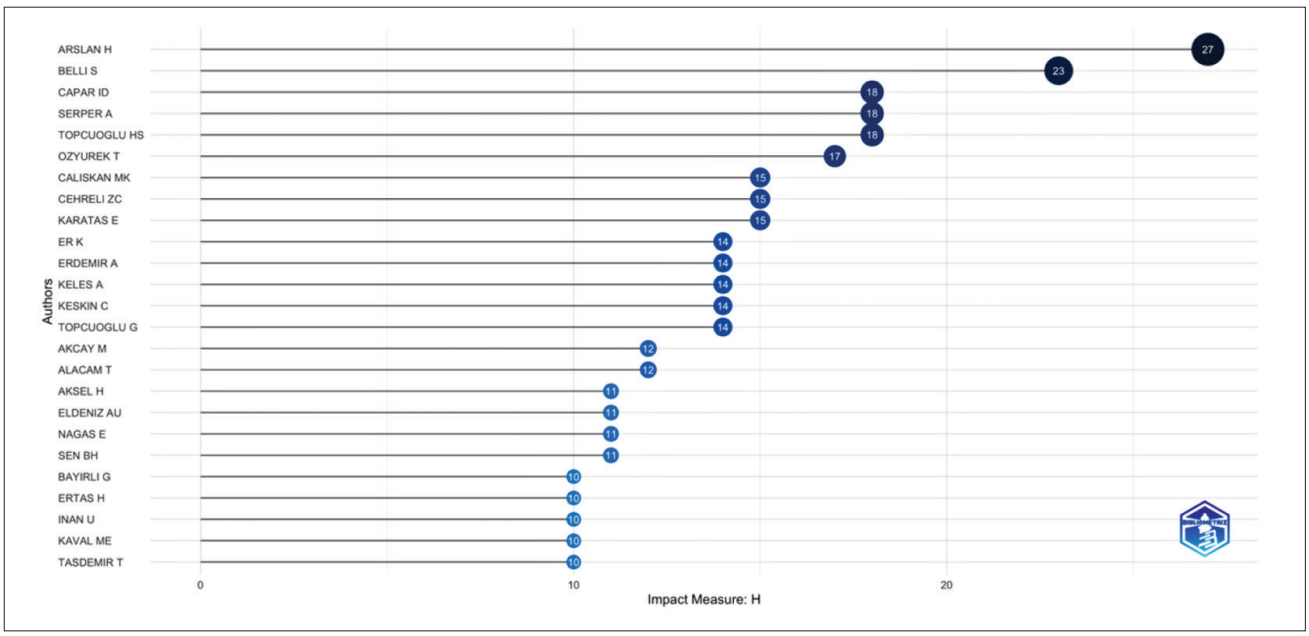

Fig. 10. Ranking of the top 25 authors based on h-index.

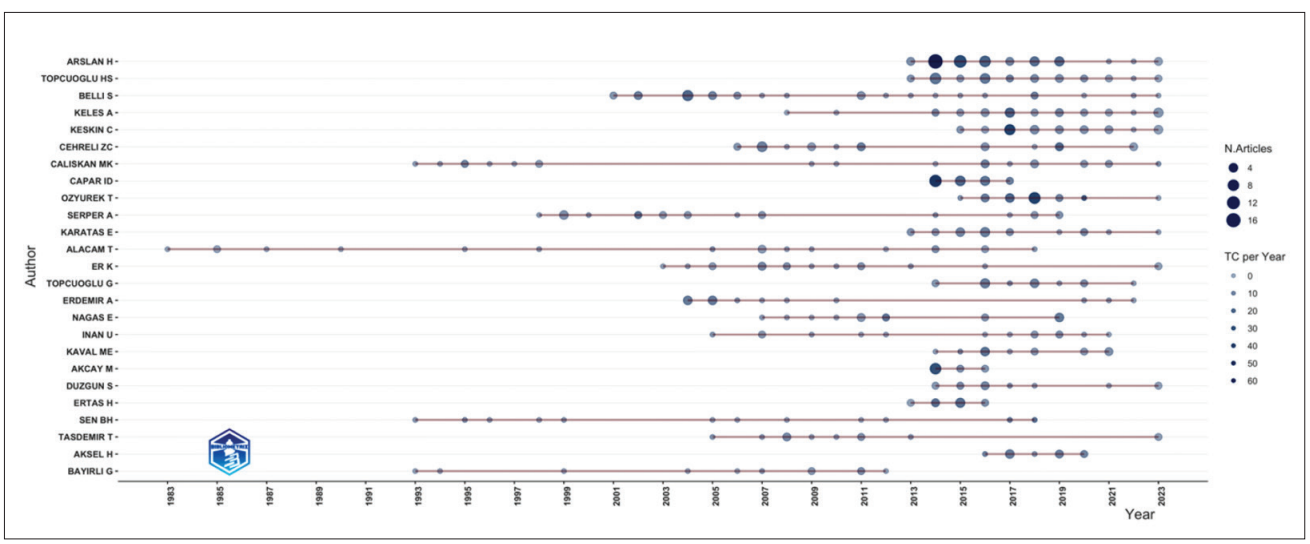

Fig. 11. Scientific productivity and citation counts of different authors over the years (N.: Number, TC: Total Citation).

Çalışkan maintained a more consistent publication output over a longer period. The 2015–2020 period appears as the most productive publishing phase for most authors.

The country most frequently collaborating on Türkiye-affiliated publications was the United States, with 57 articles. This was followed by the United Kingdom (n=29), Italy (n=25), and Iran (n=18). The collaboration network among countries is illustrated in Supplementary Figure S1.

Discussion

Bibliometrics is a valuable method that systematically analyzes scientific knowledge in a specific field, providing an overview of the topic, identifying knowledge gaps, and contributing to the development of new research ideas. It evaluates scientific impact by examining publication and citation data using statistical and mathematical methods (1). Commonly used metrics include citation analysis, h-index, impact factor, publication count, and co-authorship networks (1).

WoS database was selected for this study due to its widespread international recognition, comprehensive dataset, frequent use in academic promotions, and high compatibility with various bibliometric analysis software (6). In this context, Bibliometrix, which provides extensive analysis and visualization capabilities, was employed as the primary tool for data analysis (18).

JOE, IEJ, and AEJ are three highly regarded endodontic journals with strong impact factors. By publishing research from different regions, these journals contribute to a better understanding of the global profile of scientific production (11).

Among Türkiye-affiliated publications, JOE had the highest number of articles and h-index, while IEJ achieved the second-highest h-index. Since a high publication count alone is not sufficient to increase the h-index, additional bibliometric metrics such as average citation count should also be considered. Overall, JOE leads in terms of Türkiye-based publications, whereas IEJ provides broader international visibility and impact due to its higher global influence. The 2024 Journal Citation Reports (12) indicate that both IEJ and JOE are high-impact journals in dentistry, and research articles published in these journals hold significant scientific visibility and relevance (19).

The lower h-index of AEJ indicates that its publications receive fewer citations compared to the other journals. Although AEJ has shown growth, its scientific impact has not yet reached the desired level. Considering that AEJ has been indexed in WoS only since 2008 and is published three times per year, this outcome is expected. However, if the upward trend continues, the h-index of this journal may increase in future years.

Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology is a multidisciplinary journal covering oral surgery, medicine, pathology, radiology, and endodontics. However, after endodontics editor Lars S. W. Spångberg stepped down, publication of endodontic articles ceased in December 2011. Additionally, the publication of articles from other dental disciplines may complicate the identification of endodontic studies and limit detailed analyses. Therefore, this study focused exclusively on Türkiye-affiliated articles published in SCIE-indexed journals directly related to endodontics (JOE, IEJ, and AEJ), while the multidisciplinary journal was excluded (20). This represents one of the methodological limitations of the study.

The number of citations an article receives is influenced by multiple factors, including the quality, methodology, and originality of the study, as well as the impact factor of the journal in which it is published. Additionally, the author's reputation and collaboration network contribute to citation levels. Studies with over 100 citations are generally considered "classic" in their respective fields (21). Among the 753 articles analyzed, only 28 received more than 100 citations, indicating a limited proportion of highly impactful publications and suggesting that academic influence in the field is concentrated around specific studies. This may reflect limitations in methodological rigor, originality, or international interest in some research, whereas highly cited papers represent reference-worthy studies that have shaped the development of the field (22).

Journal-based analysis showed that the majority of the most cited articles were published in JOE, followed by IEJ. Chronological analysis indicated that articles published after 2000 demonstrated higher annual citation metrics, whereas studies from the 1990s maintained high cumulative citation counts (23). These findings suggest that foundational research in endodontics continues to exert long-term influence and remains a reference in the current literature.

Examining the 41-year period from 1983 to 2024, a notable increase in Türkiye-affiliated publications has been observed, particularly from the early 2000s onward. This growth likely reflects increasing academic interest in endodontics and strengthened collaborations among researchers.

The fluctuations and partial decline observed in Türkiye-affiliated endodontic publications after 2016 may be explained by several factors. First, the substantial increase in the number of dental faculties established in Türkiye between 2010 and 2019 may have contributed to increased academic productivity through the recruitment of

an increasing number of academicians to newly founded institutions. In particular, the publication motivation of early-career academic staff driven by academic promotion requirements appears to have supported the increase in publication numbers during this period.

However, the decline in publication trends observed after 2019 is likely to have been significantly influenced by the COVID-19 pandemic. During the pandemic, the suspension of clinical studies, restrictions on patient admissions, disruptions in laboratory activities, and the increased educational and healthcare workload of academicians may have negatively affected scientific productivity. Particularly in clinically oriented research fields, interruptions in data collection processes may explain the temporary decrease in publication output.

In addition, the initially high academic productivity observed in newly established faculties may have reached a more stable level over time, potentially contributing to the slowdown in publication growth. Furthermore, changes in academic incentive systems, economic challenges, difficulties in accessing research funding, and increased administrative and clinical workloads may also be considered among the possible factors affecting publication performance.

Nevertheless, Figure 2 demonstrates a noticeable increase in publication numbers in 2023. This recovery may be associated with the reactivation of academic activities following the pandemic, the publication of previously delayed studies, and the restoration of research infrastructure. Moreover, the increase in international collaborations and the continuation of academic performance requirements may also have supported this upward trend.

Analysis of research topics showed that the most frequently studied areas were irrigation and disinfection, root canal preparation, root canal filling, and endodontic materials. This highlights the critical role of these processes in endodontic treatment and underscores areas that require continuous development. Overall, the proportion of multidisciplinary studies was balanced, indicating that endodontics interacts not only within their own discipline but also across other fields. Expanding multidisciplinary research in the future may support the development of novel treatment methods and materials (24).

Most Türkiye-affiliated studies published in JOE, IEJ, and AEJ involved approximately four authors, suggesting that academic productivity is typically driven by small to medium-sized teams. This may be due to the nature of the field, which often requires specialized expertise for experimental or clinical studies (25).

While most studies were conducted at individual or institutional levels, international collaborations were relatively limited. Increasing international collaboration could enhance the broader academic impact of research, leading to higher citation counts and greater scientific influence (26).

The choice of research methodology directly affects the reliability of scientific findings and the strength of evidence. In evidence-based medicine, different research designs have varying levels of evidential value, with methodologically robust approaches such as systematic reviews, cohort studies, and randomized clinical trials being recommended (27). In this analysis, most publications were original research articles, likely because these articles have a higher probability of being accepted by academic journals (28).

Institutional contributions to academic productivity showed that Hacettepe, Ege, Selçuk, Erciyes, and Ondokuz Mayıs Universities ranked highest. This indicates that certain universities possess greater research capacity in endodontics and their faculty are more productive. However, to achieve a more balanced distribution of scientific output, contributions from a wider range of institutions should be encouraged.

The diversity and number of keywords can increase a manuscript's visibility by reaching a broader academic audience, potentially enhancing its citation count (29). This indicates that researchers tend to focus on specific keywords, which helps shape the overall framework of the field and reflect current research trends. Indeed, the most frequently used keyword in Türkiye-affiliated publications was endodontics (n=56), reflecting its direct relevance to the general definition of the field (30,31). Other prominent keywords, such as retreatment (n=41) and calcium hydroxide (n=38), indicate a strong research focus on retreatment procedures in cases of endodontic failure and the biomedical agents used during these processes (32–34). Subtopics including root canal disinfection, regenerative endodontics, canal filling materials, and instrument systems also emerged, demonstrating that research in endodontics concentrates on specific, clinically relevant areas.

Bibliometric analysis identified Hakan Arslan as the most prolific researcher (n=57). Considering publication count as an important indicator of academic productivity, this finding highlights Hakan Arslan's significant contribution to the field. Other highly productive authors included Hüseyin Sinan Topcuoğlu (n=33), Sema Belli (n=32), Ali Keles (n=29) and Cangül Keskin (n=29), indicating that these researchers are among the most productive in endodontics. However, academic productivity should not be assessed solely by publication count; other bibliometric metrics such as citation numbers and h-index must also be considered (3). Hakan Arslan, with 1731 total citations

and an h-index of 27, stands out both in productivity and impact. These data suggest that academic productivity and influence in endodontics are concentrated around a select group of researchers.

Analyses revealed that Hakan Arslan has a strong collaboration network and occupies a central position within it. According to the literature, such academic collaborations play a critical role in improving acceptance rates, citation counts, and overall scientific impact (35–38). Hakan Arslan's central role also suggests influence in guiding research directions and setting thematic priorities. Researchers who occupy these coordinating positions typically contribute to scientific progress both through their own work and by leading collaborative groups (39). Meanwhile, researchers such as Gamze Topcuoglu, Ertugrul Karatas, and İsmail Davut Capar showed intensive collaboration within specific groups, indicating that certain author teams focus on specialized research topics and organize work to maximize productivity (36). This structure can promote specialization and enable in-depth studies in particular subfields. Analyzing collaborations also provides insights into how academic productivity is influenced, as connections among researchers facilitate information flow, foster new research ideas, and support the dissemination of scientific knowledge (37). Researchers with extensive networks may also be more open to interdisciplinary work and take leading roles in developing new technologies, methods, or materials (40,41).

In terms of international collaborations, the United States was the most frequent partner for Türkiye-affiliated publications. This likely reflects the fact that many Turkish researchers conduct academic work in the U.S., demonstrating a tendency to collaborate with internationally recognized and respected institutions. Collaboration with European countries and Iran was also notable, suggesting that Türkiye tends to collaborate more frequently with geographically and culturally proximate countries.

Limitations of the study

One of the limitations of the present study is that only Türkiye-affiliated articles published in SCIE-indexed journals directly related to endodontics (JOE, IEJ, and AEJ) were included, while multidisciplinary journals were excluded. Although this approach enabled the creation of a more homogeneous dataset and allowed for a focused evaluation of endodontic research productivity, collaboration patterns, and publication trends, it may also have resulted in the exclusion of potentially relevant endodontic studies published in multidisciplinary dental or medical journals. Because multidisciplinary journals contain publications from a broad range of specialties, accurately identifying and classifying endodontic studies within such journals may be challenging and could reduce the specificity and reliability of field-focused bibliometric analyses. Therefore, the findings of the present study should be interpreted within the context of this methodological limitation.

Conclusion

The bibliometric analysis of Türkiye-affiliated publications in the three highest-impact endodontic journals provides a comprehensive overview of academic productivity and current research trends in Türkiye. These findings serve as a valuable reference for guiding future research efforts. Future studies should place greater emphasis on increasing randomized controlled clinical trials, systematic reviews, and meta-analyses to strengthen evidence-based endodontic practice. In addition, strengthening inter-university research networks and promoting multicenter collaborations are essential for enhancing scientific cooperation, while structured mentoring programs may support the development of early-career researchers. Expanding international collaborations, particularly while maintaining and developing partnerships with leading countries in the field, is also recommended. Emerging research areas such as digital endodontics, regenerative therapies, and biomaterials should be further prioritized to support technological advancement in the discipline. Furthermore, promoting open-access publishing and the dissemination of research findings through digital and social media platforms may enhance scientific visibility and impact. Finally, the establishment of targeted national funding programs dedicated to evidence-based clinical research in endodontics is encouraged to support high-quality scientific production.

* This study was derived from a postgraduate thesis. The thesis has not been previously published in any journal or other scientific publication.

*This study was presented as an oral presentation at the 16th International Turkish Endodontic Association Congress held in Antalya on May 25-28, 2025.

Authorship Contributions: Concept: M.K.; Design: M.K.; Supervision: T.T.; Fundings: M.K., T.T.; Materials: M.K., T.T.; Data: M.K.; Analysis: M.K., T.T.; Literature Review: M.K.; Writing: M.K.; Critical Revision: M.K., T.T.

Acknowledgements: *Prof. Dr. Tayfun Alaçam shared the following anecdote during a conversation with T.T., one of the authors of this study: "When our first article affiliated with a Turkish institution was published in the Journal of Endodontics in 1983, there were only eight dental schools in Tür-

kiye. When copies of that issue reached the university libraries, Prof. Dr. Gündüz Bayırlı sent me a letter expressing how proud and happy they were. That was an incredibly exciting and motivating moment for me." On this meaningful occasion, we would like to express our sincere gratitude to all endodontists who have contributed to the Turkish endodontic community's esteemed position on the international stage. While commemorating with respect and gratitude the academics who are no longer with us, especially Prof. Dr. Gündüz Bayırlı, we also wish all Turkish endodontists many more years of success, scientific productivity, and continued contribution to the advancement of knowledge.

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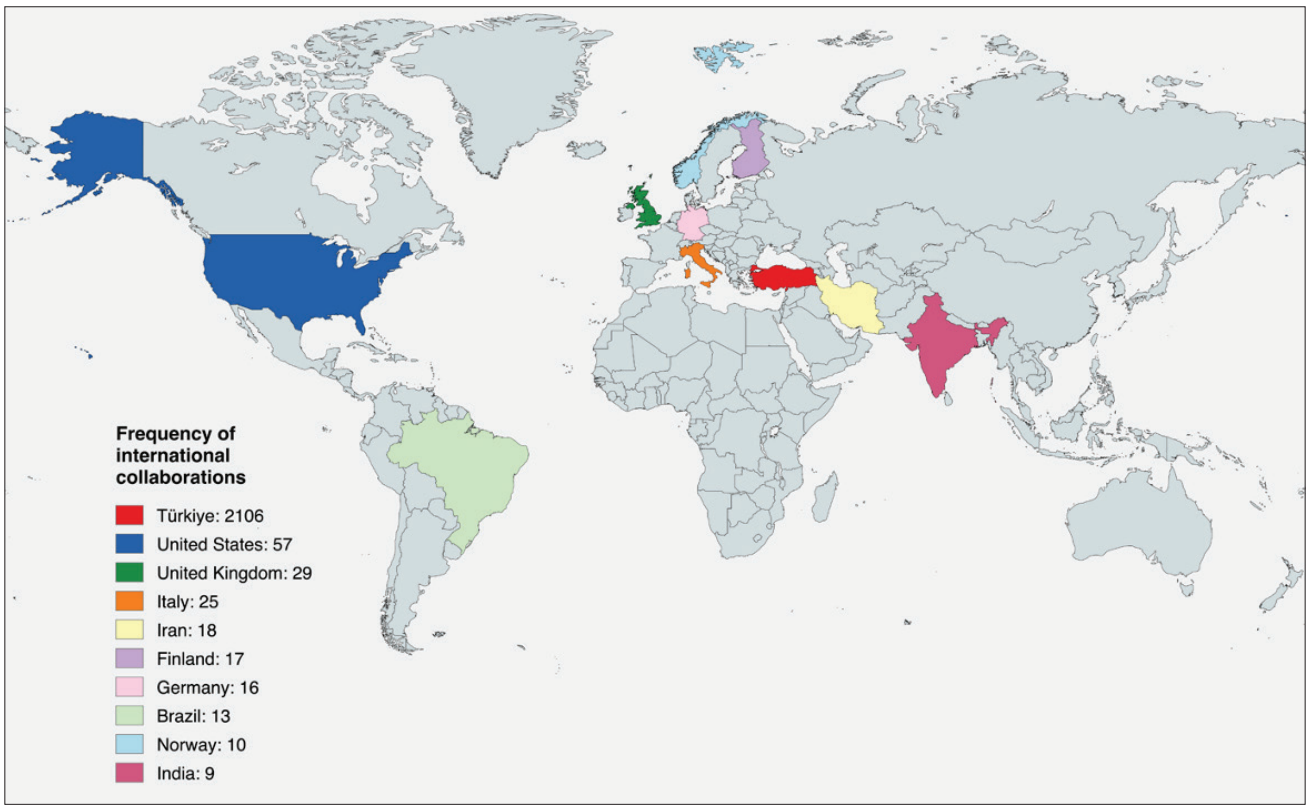

Supplementary Fig. S1. Geographic distribution of the top 10 countries collaborating on publications.

CASE REPORT

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Management of a Molar Tooth with External Inflammatory Root Resorption by Intentional Reimplantation: A Case Report

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External inflammatory root resorption (EIR) is a pathological process that typically develops as a result of trauma, infected necrotic pulp, or orthodontic forces causing damage to the periodontal tissues. In this case report, intentional reimplantation (IR) was performed on a 42-year-old systemically healthy male patient presenting with EIR and a periapical lesion in the right mandibular second molar. The treatment involved orthograde root canal retreatment followed by tooth extraction, microscopic evaluation of the root surfaces, apical resection, retrograde filling with mineral trioxide aggregate, and reimplantation of the tooth into its socket. All extraoral procedures were completed within 12 min, during which the root surfaces were continuously irrigated with sterile saline. Clinical and radiographic follow-up revealed a reduction in the lesion size and that the tooth remained asymptomatic and functional. IR is considered an effective and tooth-preserving approach in the management of EIR.

Keywords: Intentional reimplantation; external inflammatory resorption; periapical lesion; mineral trioxide aggregate.

Introduction

External inflammatory root resorption (EIR) begins either as a result of damage to the protective precementum layer on the external root surface or as a consequence of the root canal microbiome associated with an infected necrotic pulp (1). The causes of EIR may include trauma, necrotic tissues, infections of bacterial origin, lesions such as cysts or tumors, or the destruction of the periodontal ligament by inappropriate orthodontic forces. In addition, systemic diseases such as hyperparathyroidism, hypoparathyroidism, and Gaucher's syndrome may also contribute to its development (2). This pathological process is frequently observed radiographically, particularly in combination with infected teeth presenting signs of chronic apical periodontitis (3). In cases involving complex root canal morphologies, anatomical variations, and advanced external resorption, conventional endodontic treatment methods may prove insufficient; in such situations, endodontic surgery becomes necessary to enhance the likelihood of treatment success.

Mineral trioxide aggregate (MTA) is a calcium silicate based cement that is preferred in various clinical applications such as perforation repair, apexification, and retrograde fillings, owing to its high biocompatibility, low solubility, excellent sealing ability, and capacity to form a chemical bond with dentin (4-6). Endodontic studies have demonstrated that the use of MTA in EIR has been largely successful (7,8). The primary reasons for its application in EIR treatment include its ability to create an

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apical plug, high biocompatibility, antimicrobial effect, radiopacity, and its capacity to promote regeneration in periapical tissues such as the periodontal ligament, bone, and cementum (9).

Intentional reimplantation (IR) is a treatment method based on the deliberate and atraumatic extraction of a tooth, followed by direct visualization of root surface pathologies under magnification and illumination, the application of necessary endodontic procedures, and subsequent reinsertion of the tooth into its original socket (10). The indications for this method include the management of iatrogenic or external root perforations, the presence of complex root canal anatomies, and the treatment of apical periodontitis cases that fail to heal despite conventional root canal therapy or apical surgery. It is also indicated for the removal of foreign materials in the periapical region that cannot be managed by an orthograde approach, as well as for the treatment of periradicular cystic lesions (11).

The most significant barrier to the routine implementation of IR in clinical practice is the wide variation in reported success rates in the literature (10,12,13), together with the lack of a standardized protocol and prognostic follow-up criteria for the procedure (12). Several complications may arise following intentional replantation, and the most commonly reported adverse outcomes include ankylosis, replacement resorption, and failed reimplantation. Ankylosis occurs when the periodontal ligament cells lose their vitality and the root surface becomes fused directly to the alveolar bone; this condition is particularly likely in cases with prolonged extraoral time (14). Replacement resorption is characterized by the gradual resorption of cementum and dentin on the root surface, which are subsequently replaced by alveolar bone, typically resulting in long-term loss of tooth function (15). Clinically, failed reimplantation manifests as pain, mobility, periodontal pocket deepening, or persistent periapical pathology (16).

The present case report aims to demonstrate that, when performed under appropriate indications and clinical conditions, intentional reimplantation has considerable potential for success, as supported by the 1-year follow-up presented in this case.

Case Presentation

The current case report was prepared in accordance with the Preferred Reporting Items for Case Reports in Endodontics (PRICE) 2020 guidelines. The PRICE 2020 flowchart presents the complete case report summary (Fig. 1).

In 2024, a 42-year-old systemically healthy male patient presented to the Department of Endodontics, Faculty of Dentistry, Cukurova University. Radiographic examination revealed inadequate root canal treatment in the right mandibular second molar (tooth 47), EIR in the mesial root, and a periapical lesion. Cone-beam computed tomography (CBCT) examination confirmed the presence of EIR in the mesial root of the right mandibular second molar , perforating the buccal bone, as well as a lesion measuring approximately 10×7×7 mm involving the periapical region and encompassing both roots. Based on these findings, the tooth 47 was diagnosed with chronic apical periodontitis associated with EIR and inadequate root canal treatment.

In order to repair the irregular and resorbed hard tissues located in the apical one-third of the mesiobuccal root surface, to minimize potential damage to the mandibular canal, and to enable curettage of the granulation tissue in the periapical region, IR was planned as the treatment option. The option of apical surgery was also presented to the patient, and the potential risks and complications of both treatment approaches were explained in detail. Based on the patient's preference, IR was selected as the treatment

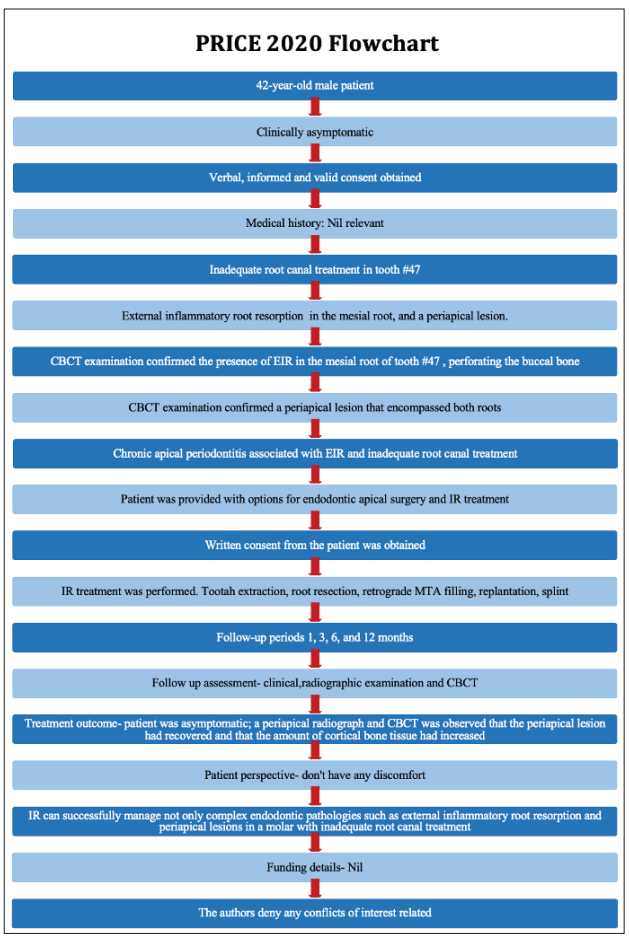

Fig. 1. PRICE 2020 flowchart.

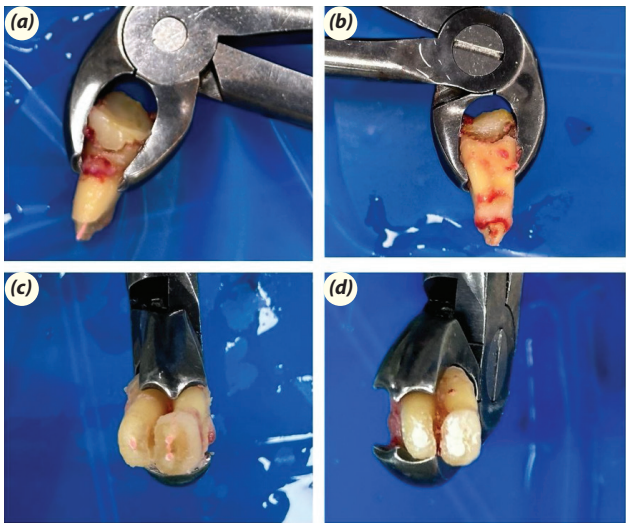

Fig. 2. Implementation of the IR protocol. **(a)** Image of the distal root after extraction, **(b)** Image of the mesial root after extraction, **(c)** Root-end resection at 0° parallel to the occlusal plane, **(d)** Placement of retrograde filling with MTA.

modality, and written informed consent was obtained. Following anesthesia of the right mandibular second molar with 4% articaine hydrochloride containing 1:100,000 epinephrine (Ultracain D-S; Sanofi, Paris, France), an access cavity was prepared under rubber dam isolation using sterile diamond burs, and the 25.04 retreatment file system (Perfect Endo, Wuhan, China) was employed for the removal of gutta-percha. During the removal of the root canal fillings, a file fracture occurred in the apical third of the distal canal. The working length of the mesiobuccal canal was determined up to the resorption area using a size 25 K-type hand file, while apical patency in the mesiolingual canal was achieved with a size 10 K-type hand file hand file before establishing the working length, which was confirmed with periapical radiography. The mesiolingual canal was prepared with a Reciproc Blue R25 file (25/.08) (VDW, Munich, Germany), whereas the mesiobuccal and distal canals were prepared with a Reciproc Blue R40 file (40/.06) (VDW). Throughout the procedure, each canal was irrigated with 10 mL of 2.5% NaOCl. For the final irrigation, each canal was rinsed with 2 mL of 17% EDTA, followed by 5 mL of saline solution to remove the EDTA from the root canal system. After completion of the irrigation protocol, the root canals were dried with sterile paper points and obturated using gutta-percha and AH Plus, an epoxy resin–based sealer, by means of the lateral condensation technique. After the canal orifices were sealed with resin-modified glass ionomer cement, the coronal restoration was completed using composite resin, and occlusal adjustments were performed. The patient was scheduled for IR the following day. On the next day, for preoperative disinfection of the surgical site, the patient rinsed with 0.12% chlorhexidine gluconate, after which mandibular block anesthesia was administered to the relevant area using 4% articaine hydrochloride with 1:100,000 epinephrine (Ultracain D-S; Sanofi) In order to minimize damage to the periodontal ligament, the use of a dental elevator was kept to a minimum, and the tooth was carefully extracted with the aid of a mandibular molar forceps in an atraumatic manner. However, fracture occurred in the distal apical third curvature region, leaving that portion within the socket. Following extraction, the crown separated from the root; nevertheless, as it remained in a restorable condition, the procedure was continued. After the remaining root fragment was removed with the aid of an elevator and a periodontal curette, the granulation tissues within the socket were eliminated. Subsequently, to prevent contamination of the extraction socket, it was covered with sterile gauze.

The extracted tooth was held at the cementoenamel junction with forceps and examined under magnification using a dental operating microscope. The granulation tissues on the mesial root were removed with ultrasonic tips under saline irrigation, and the root end was resected at 0 degrees, parallel to the occlusal plane, at a depth of 3 mm. The distal root end was also flattened parallel to the occlusal plane, and retrograde cavities with a depth of 3 mm were prepared in the roots using ultrasonic tip (E4D, Woodpecker, Guilin, China). Subsequently, retrograde fillings with a depth of 3 mm were placed using MTA (MTA Plus, PrevestDenPro, Jammu, India). The tooth was then repositioned into the socket by finger pressure, and its placement within the alveolar socket was confirmed by a periapical radiograph (Fig. 2).

All extraoral procedures were completed within 12 min, during which continuous saline irrigation of the root surface was performed by an assistant using 10 cc syringes. Following reimplantation, eight sutures were placed to preserve the anatomical integrity and tissue adaptation of the papillae and surrounding soft tissues. In the postoperative period, the patient was advised to avoid biting with the treated area and to brush gently with a soft toothbrush. For infection prophylaxis, amoxicillin 1000 mg was prescribed twice daily for 7-day, and ibuprofen 100 mg was prescribed as needed to provide analgesia. At the 10-day follow-up visit, soft tissue healing was observed, and the treated tooth was found to be asymptomatic. After suture removal, the coronal restoration was completed, and the patient was scheduled for follow-up at 1-, 3-, 6-, and 12-months to monitor the treatment process (Fig. 3).

At the 1-month follow-up, the treated tooth was functional, asymptomatic, and exhibited normal mobility. At the 3- and 6-month follow-ups, the tooth remained clinically as-

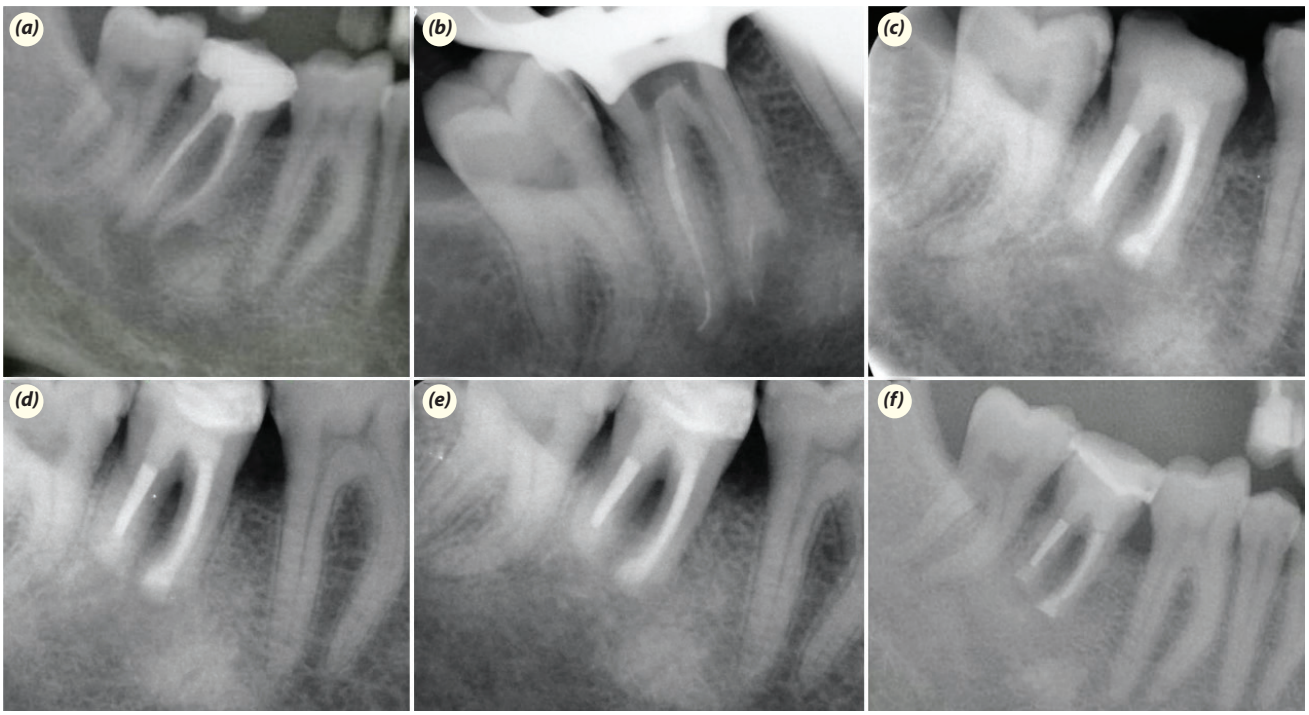

Fig. 3. Radiographic images. **(a)** Preoperative, **(b)** A fractured file in the distal root during retreatment, **(c)** Immediate postoperative radiograph after IR, **(d)** 3-month follow-up, **(e)** 6-month follow-up, **(f)** 12-month follow-up.

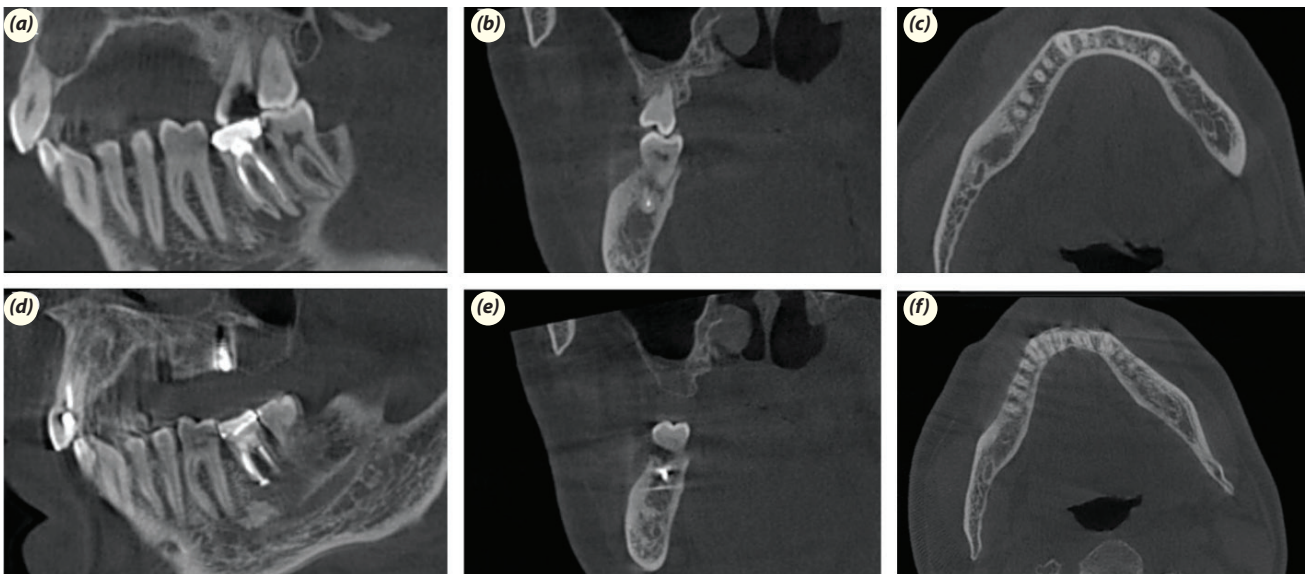

Fig. 4. CBCT images. Baseline periapical lesion in; **(a)** Sagittal, **(b)** Coronal, and **(c)** Axial views. One-year follow-up in **(d)** Sagittal, **(e)** Coronal, and **(f)** Axial views.

ymptomatic, and periapical radiographs revealed a marked reduction in lesion size. At the one-year follow-up, both periapical radiography and CBCT assessments were performed, demonstrating healing of the periapical lesion and an increase in the amount of cortical bone tissue (Fig. 4).

Discussion

EIR can occur at any level of the root and may remain clinically asymptomatic, being detected incidentally during routine radiographic examination (17). When the etiology of EIR is identified, treatment should first be-

gin with the elimination of the causative factors, such as discontinuing mechanical forces, extracting the impacted tooth, or removing cysts, tumors, or necrotic tissues (18). In the presence of EIR, the granulation tissue in the affected area must be carefully removed, and the defect should be sealed with biocompatible materials that also provide leakage prevention (19). In this case, the detection of extensive EIR in the apical third of the mesial root along with a large lesion within the alveolar bone was decisive in treatment planning. To repair the irregular and resorbed hard tissues in the apical third of the root, to minimize potential damage to the mandibular canal, and to enable curettage of the granulation tissue in the periapical region, IR was chosen as the treatment option.

The hydrophilic nature of MTA allows the material to set even in moist environments, making it suitable for procedures such as endodontic apical surgery and IR, where blood and moisture are present (20). Accordingly, in our case, MTA was chosen as the retrograde filling material.

Endodontic apical surgery, as it involves invasive procedures such as flap elevation, hemostasis, and removal of a certain amount of bone tissue, is a more complex and time-consuming surgical procedure compared to IR. In contrast, IR does not require any flap operation or intervention on the alveolar bone, allowing the treatment process to be completed in a shorter time and with a less invasive approach (21). One of the major advantages of this method is that it enables direct observation of all dental hard tissues under magnification while causing minimal trauma to the surrounding tissues.

Conventional radiography provides limited information for the accurate identification and determination of the extent of EIR, whereas advanced imaging modalities such as CBCT allow for a more comprehensive and detailed assessment of resorptive lesions. In the present case, CBCT played a critical role in treatment planning by clearly demonstrating the extent of the resorption (22).

According to Grossman, periodontal ligament (PDL) cells can remain viable for approximately 15–20 min, and if the tooth is replanted into its socket under appropriate conditions within this period, healthy reattachment between the alveolar bone and PDL cells can be achieved (10). For this reason, in the present case, the extraoral time was limited to 12 min.

After tooth extraction, various clinical approaches have been proposed to preserve the viability of periodontal ligament cells and to maintain the root surface in a moist environment. Some clinicians prefer to wrap the tooth in sterile gauze moistened with saline to achieve this condition, whereas others recommend holding the tooth only at the cementoenamel junction and keeping the root surface continuously irrigated with saline throughout the procedure (12). In the present case, we performed the clinical procedure in accordance with the latter approach.

Regarding splint application after reimplantation, the literature presents differing opinions. While some clinicians apply a splint only when the tooth exhibits significant mobility, others prefer to use splinting in all cases (11). According to a recent meta-analysis, IR provides a mean tooth survival rate of approximately 88% (23). In addition, a prospective cohort study reported a 12-year cumulative retention rate of 93% for IR, demonstrating that this treatment option is promising in terms of long-term success (24).

Conclusion

This case report demonstrates that IR is an effective and conservative treatment option in the management of complex endodontic pathologies and complications that may arise during treatment. However, as failure may emerge years later in such procedures, the patient should be followed up in the long term to obtain a more definitive result.

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