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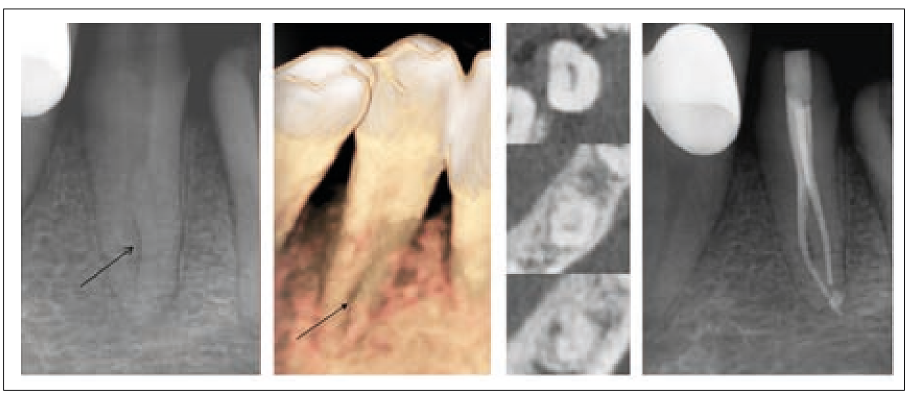

Original Articles

The outcome of root canal treatment with a calcium silicate-based sealer of necrotic teeth: a retrospective assessment

Relationship between Inflammation site and apical periodontitis in patients with severe endodontic pain

Setting time of calcium silicate-based sealers at different acidic pHs

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Case Reports

Intentional replantation for the management of an external cervical root resorption: a case report

Review Article

Diversity of root canal morphology in mandibular premolars and its treatment strategies

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Contacts
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Email: *sie@mvcongressi.it*
PEC: *segreteria.sie@pec.segreteriasie.it*
Site: www.endodonzia.it
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Sandro Rengo
Editor-in-Chief
Giornale Italiano di Endodonzia
E-mail address
editor.giornale@endodonzia.it

Editorial

Full of past certainties and looking towards the future

The 38th edition of National Congress of the Italian Society of Endodontics (SIE) represents, as usual, a fixed appointment of the society cultural program. The event is hosted in Bologna from 9 to 11 November 2023 and develops the topic of "SMART ENDO – Certainties Vs Innovation" aiming at assessing the certainly of traditional endodontics with a modern point of view through the introduction of innovative instruments, materials and devices. The contrast between past and future will create interesting discussion and different opinions with the aim to improve the clinical endodontic realty and the predictability of outcomes over time. Specifically, employment of 3D technology, use of biomaterials and innovation of instruments are some of the debated topics by highly qualified endodontists.
Contextually, the present issue of Giornale Italiano di Endodonzia includes several scientific papers that have developed the same themes, focusing on future innovations based on fundamental principles of endodontics, as calcium-silicate based cements and their performances, in vivo use of newly developed Ni-Ti instruments and the chance to revascularize necrotic immature permanent dental elements. Moreover, an interesting bibliometric analysis on the current knowledges and future perspectives of endo-periodontal lesions has been conducted, presenting a highly debated topic of daily clinical practice.
In an ever increasing "smart" realty, even endodontics is advancing, without forget its focus, as the achievement and maintenance of clinical success over time. Regarding progress, I'm proud to announce the IF obtaining by the present Journal that marks a turning point of its global editorial positioning.
Finally, I take the opportunity to do my best congratulations and wish good job to Prof. Gianluca Gambarini president elect of European Society of Endodontology (ESE) e to Prof.ssa Elisabetta Cotti president elect of International Federation of Endodontic Association (IFEA), that will represent Italian endodontics at an international level.

Peer review under responsibility of Società Italiana di Endodonzia.

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ORIGINAL ARTICLE

Influence of different obturation techniques on the bond strength of the filling material to the root canal dentin and the quality of the final obturation

ABSTRACT

Aim: *This study aimed to evaluate the influence of different obturation techniques on the bond strength (BS) of the filling material to the root canal dentin and the quality of the final obturation.*

Methodology: *Forty mandibular premolars extracted from human had their root canals prepared, irrigated, dried, and distributed into four groups, according to the obturation technique performed (n=10): Lateral compaction (G_{LC}); Single-cone (G_{SC}); Tagger's hybrid (G_{TH}); and Continuous wave condensation (G_{CW}). Radiographic images were obtained and assessed before and after the obturation procedures. Afterward, roots were transversally sectioned in 1-mm slices and analyzed regarding the obturation quality, followed by push-out test and failure mode analysis. Data were statistically analyzed by 2-way ANOVA and post-hoc Tukey test; and by Kruskal-Wallis and post-hoc Games-Howell and Sidak tests.*

Results: *All groups presented highest BS mean values in the apical third ($p<0.05$). Regardless of the root third, G_{CW} had the lowest BS values ($p<0.05$). Radiographically, G_{LC} presented higher number of failures compared to G_{TH} and G_{CW} ($p<0.05$); and G_{TH} showed higher values of overfilling ($p<0.05$). For the stereomicroscope analysis, G_{TH} had the largest filled area, while G_{LC} ($p=0.001$) presented the smallest sealed area.*

Conclusions: *The different obturation techniques of the root canal influenced the quality and BS of the filling material to the root dentin. Tagger's hybrid technique showed the best filling quality, with a larger filling area, however it presented a greater amount of overfilling. The continuous wave condensation technique provided less adhesion between the filling material and the root canal dentin.*

Ihan Vitor Cardoso[1]

Matheus Pompeo Caldas Silveira[1]

Gabriela Rover[2]

Lucas da Fonseca Roberti Garcia[1]

Eduardo Antunes Bortoluzzi[3]

Cleonice Silveira Teixeira[1*]

[1]Department of Dentistry, Endodontics Division, Federal University of Santa Catarina, Florianópolis, Santa Catarina, Brazil

[2]Dentistry Division, Florianópolis Air Base, Brazilian Air Force, Santa Catarina, Brazil

[3]Department of Diagnosis & Oral Health, Division of Endodontics, School of Dentistry, University of Louisville, Louisville, KY, USA

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KEYWORDS *Bond strength, obturation quality, obturation techniques, root canal obturation.*

Corresponding Author

Cleonice da Silveira Teixeira | Department of Dentistry - Endodontics Division, Health Sciences Center, Federal University of Santa Catarina. Adress: Campus João David Ferreira Lima, Trindade, Florianópolis, Santa Catarina | Brazil

Telephone/Fax: +55 48 3721-5840, +55 48 3721-9520 E-mail: cleonice.teixeira@ufsc.br / cleotex@uol.com.br

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Introduction

The success of endodontic treatment depends on the complete debridement, the elimination of pathogenic microorganisms and the three-dimensional filling of the root canal space (1). An adequate root canal filling prevents the penetration of oral microorganisms in periradicular tissues and vice-versa (1).
Different types of root canal sealers may be used in combination with gutta-percha cones to obturate the root canal system after biomechanical preparation (2). This association is necessary, as gutta-percha cones cannot adhere to the dentin surface (2). The sealer, in addition to ensuring the cones adhesion, is the main responsible for filling irregularities, ramifications and apical delta filling, as well as other hard-to-reach areas (3).
The obturation technique may also affect the quality and adhesion between the filling material and the root canal dentin (4). The cold lateral compaction technique is still widely used and it consists of using a master gutta-percha cone, complemented by accessory cones, wrapped in the sealer (5). In the last years, the single-cone obturation technique has been proposed as an easy and faster procedure (5). In this technique, the root canal is obturated using a single master gutta-percha cone of taper similar to the last rotary/reciprocating NiTi instrument used during biomechanical preparation (5).
Thermoplastic techniques may also be performed for root canal obturation (6), which require less working time when compared to the conventional cold lateral compaction technique (6). These techniques allow the compaction of heated gutta-percha cones against the irregularities of the root canal walls, avoiding empty spaces (6).
There are several methods to assess the quality of root canal obturation in laboratory studies (7-12). However, clinically, the evaluation is performed through radiographic examination after root canal filling procedure (10). Usually, these radiographs are performed in the buccolingual direction, which limits this evaluation (10,13). Laboratory studies have the advantage of allowing inter and intra-area comparisons of a given treatment (11). After obtaining the images and using specific softwares for analysis it is possible to accurately measure the area filled by gutta-percha and sealer, as well as the failures present at the interfaces between sealer and gutta-percha, or between sealer and dentin (11).
The adhesion of the filling material to the root canal dentin is the result of a physical-chemical interaction throughout the canal interface (3), which comes from the obturation technique and the filling materials used in this process. As already was noted, the different obturation techniques have several distinct characteristics and the pressure applied in these procedures influences the mechanical interconnection between the filling material and the root canal dentin (6).
Therefore, the objective of this study was to evaluate the influence of different root canal obturation techniques on filling quality and bond strength (BS) to the root canal dentin. The null hypothesis tested was that different obturation techniques would not influence the quality or BS of the filling material to the root canal walls.

Materials and Methods

Sample Size Calculation
The sample size was estimated based on previous studies (6, 10, 14) using G*Power software (G*Power 3.1 software for Windows; Heinrich Heine-Universität, Düsseldorf, Germany). An alpha-type error of 0.05 and power beta of 0.80 were specified, and resulted an ideal sample of 40 teeth (at least 10 teeth were allocated per group).

Sample Selection and Preparation
This study was previously approved by the Ethics Committee of Federal University of Santa Catarina (Protocol nº 2.651.307). The experimental design of the study is presented in a flowchart (Figure 1). Forty human mandibular premolars were extracted for reasons unrelated to this study. Right after the extraction procedure, the teeth were cleaned with ultrasonic scalers,

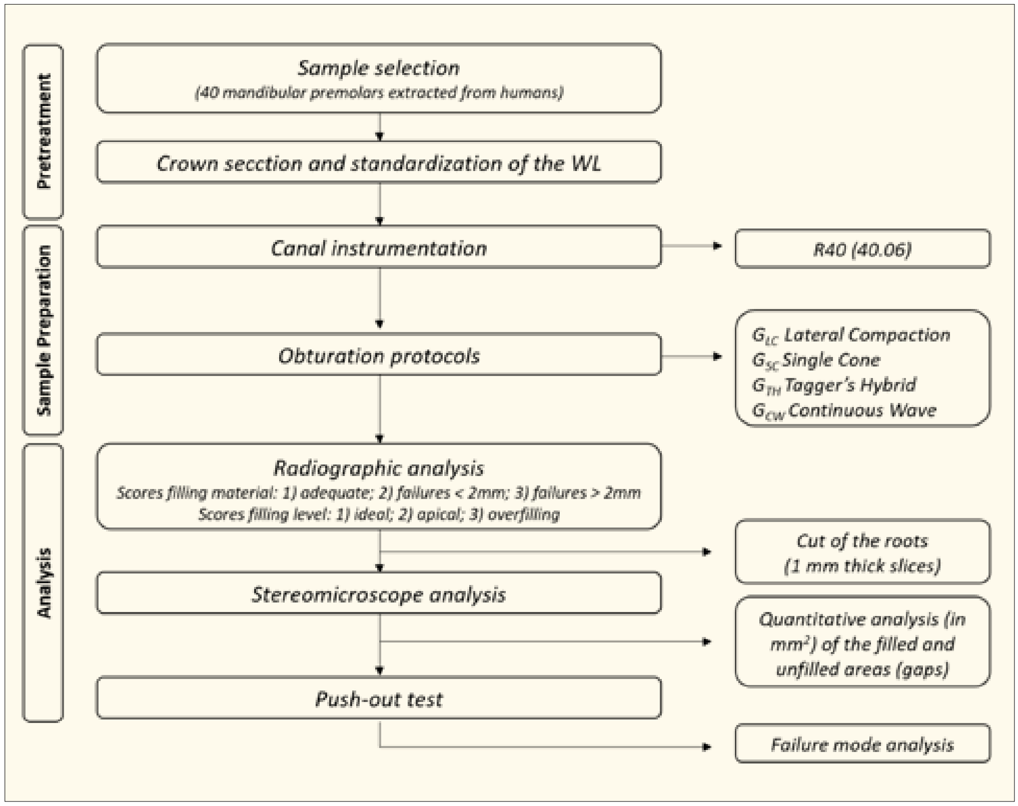

Figure 1
Flowchart of the experimental design.

rinsed with distilled water, and stored in 0.05% thymol at 4 ºC to prevent bacterial growth until use. The teeth were radiographed in both, mesiodistal and buccolingual, directions and examined in stereoscopic lens under ×4 magnification (Illuminated Magnifying Glass, Tokyo, Japan). Teeth with a single, straight and circular cross section root canal, free of caries or previous restorations, without curvatures or microcracks, and a fully formed apical foramen were selected. The teeth had their crowns sectioned by a double-sided diamond disc (Brasseler Dental Products, Savannah, GA, USA) under air/water spray copious cooling. The root canal length was standardized at 15 mm and confirmed by introducing a size 15 Flexofile instrument (Dentsply Maillefer, Tulsa, OK, USA) until its tip reached the apical foramen. The working length (WL) was established by subtracting 1 mm from the root canal length. After, the apexes of the roots were protected with sticky wax (Lysanda, São Paulo, SP, Brasil), to allow the irrigation solution to flow and to simulate the presence of tissue in the periapical region.

The root canals were prepared with Reciproc R40 (40/0.06) instrument (VDW GmbH, Munich, Germany), driven by an electrical motor (VDW Silver, VDW GmbH), according to the manufacturer's instructions. At each removal of the instrument for cleaning, the root canals were irrigated with 2 mL of 1% sodium hypochlorite (NaOCl) solution using a syringe with NaviTip 30-gauge needle (Ultradent, South Jordan, UT, USA) inserted up to 2 mm from the WL. As final irrigation, 3 mL of 17% ethylenediaminetetraacetic acid (EDTA) was used for 3 min, followed by 3 mL of 1,0% NaOCl for 3 min and rinsing with 5 mL of distilled water. After final irrigation, root canals were dried using a size 40 absorbent paper points (Dentsply Maillefer) inserted up to the WL.

Obturation Protocols

In all samples, it was used an epoxy-resin based sealer (AH Plus, Dentsply De Trey, Konstanz, Germany), which was manipulated according to the manufacturer's recommendations. Also, prior to obturation, the master cones were selected for each root canal and adapted in the WL. Periapical radiographs in the mesio-distal and buccal-lingual directions were taken to confirm the measurement and serve as the gold standard for subsequent analyses. Then, the roots were randomly assigned to the following four experimental groups, according to the obturation protocols performed (n=10):

Group of Lateral Compaction (G_{LC})

The sealer was taken to the canal with the aid of a size 40 gutta-percha cone (Dentsply Maillefer), which was coated with endodontic sealer and inserted using circumferential movements in the root canal until reach the WL. Then, a 25 mm finger spreader (B, Dentsply Maillefer) calibrated 2 mm from the obturation length was used laterally to the master cone, followed by the insertion of accessory cones (F, Dentsply Maillefer) coated with endodontic sealer, until the root canal was completely filled.

Group of Single-Cone (G_{SC})

A single gutta-percha cone of the Reciproc system (R40, VDW GmbH) was used to fill the root canal, which was coated with endodontic sealer and inserted using circumferential movements in the root canal until reach the WL.

Group of Tagger's Hybrid Technique (G_{TH})

After the insertion of the master gutta-percha cone of the Reciproc system (R40, VDW GmbH) and two accessory cones (F, Dentsply Maillefer) coated with sealer, the McSpadden condenser (50, Dentsply Maillefer) was introduced, and rotated clockwise until it reached 6 mm up to the WL. After obtained the plasticization of the filling material, the condenser was removed from the root canal by turning.

Group of Continuous Wave Condensation (G_{CW})

A System B condenser (Analytic Sybron Dental Specialties, Orange, CA, USA) that penetrated up to 6 mm above the WL was selected. After the sealer placement into the root canal by using a master gutta-percha cone of the Reciproc system (R40, VDW GmbH) until reaching the WL obturation length (1 mm from the root canal length), the System B was adjusted to 200 °C, activated with a touch and taken to the root canal until the previously calibrated measurement. After 5 seconds, the condenser was removed and, subsequently, created a space that was filled with the aid of the injection gun (Obtura Spartan, Fenton, MO, USA), until the root canal was complete with thermoplasticized gutta-percha in its middle and cervical thirds.

In all groups, prior to the obturation procedure, the master cone was adapted in the WL and a radiographic examination was performed to confirm the measurement. After the obturation procedure, a new radiographic examination was performed to assess the obturation quality.

The gutta-percha was cut with a heated plugger (Odous de Deus, Belo Horizonte, MG, Brazil) in the root canals entrance, and after vertical compaction, the roots was sealed with a temporary restorative material (Citodur, Dorident, Austria) and the specimens were stored in an oven at 37 °C and 100% relative humidity for 24 hours to allow the sealer setting.

Radiographic Analysis

The radiographs obtained after obturation were scanned (HP ScanJet g4010, Hewlett-Packard Company, Palo Alto, California, USA) and analyzed using the HP ScanJet-Document Scanners software (Hewlett-Packard Company, Palo Alto, California, USA).

At each root canal third (coronal, middle and apical), two blindly and independently examiners (*Cronbach's* alpha=0,957) assessed the quality of the root canal obturation according to the following scores: 1) adequate obturation of the root canal by the filling material, no failures; 2) presence of failures within or near to the root canal walls, however, less than 2 mm in length; 3) failures within the filling material or near to the root canal walls, more than 2 mm in length.

In order to assess the apical level of the filling material, the following scores were considered: 1) ideal level, 1 mm below the root apex; 2) apical level, filling material at the root apex (0 level); 3) overfilling, presence of filling material beyond the root canal limits.

Stereomicroscope Analysis

The roots were transversely sectioned in relation to their long axis with a diamond saw blade (South Bay Technology, San Clement, CA, USA), coupled to a metallographic cutter (Isomet 1000, Buehler, Lake Forest, IL, USA), obtaining 1 mm-thick slices. The first and last slices were discarded from the final sample. Slices were selected from each third of the root (coronal, middle and apical; at 2, 5 and 8 mm from the apex, respectively), which had thickness and obturation radius (major radius and minor radius) measured with a digital caliper (Mitutoyo vernier caliper, Mitutoyo Inc., Kawasaki, Japan).

The slices were subjected to a careful visual exam in a ×40 magnification stereomicroscope (SteREO Discovery.V12, Carl Zeiss, Jena, Germany), and areas of interest were photographed. Each image analysis was performed with the aid of the Axiocam Program (Carl Zeiss, Jena, Germany) to identify the presence of failures at the filling material interface (gaps and bubbles, lack of contact between the filling material and root canal dentin, and between the sealer and the gutta-percha). The area of the root canal in each slice was initially measured in mm^2. The eventual failures (unfilled areas/gaps) observed at the root canal dentin interface, or within the filling material, were also measured in mm^2.

Push-Out Test

In order to determine the interfacial BS between the filling material and the root canal dentin the push-out test was performed (2-4). Six slices per root (two from each root canal region), which had been previously analyzed under stereomicroscopy, were selected to perform the push-out test. Each slice was marked on its apical side and individually fixed with its coronal surface facing down, in a stainless-steel base containing a 2.5 mm diameter hole in its center, which was attached to the lower portion of a universal testing machine (Instron, Model 4444; Instron, Canton, MA, USA). A compressive force was applied to the apical side of each slice by using cylindrical plungers (with tip diameter ranging from 0.6 mm to 1.0 mm, selected according to the root canal diameter of the tested slice) attached to the upper portion of the Instron machine. A crosshead speed of 0.5 mm/min was applied until bond failure occurred.

To express the BS in megapascals (MPa), the maximum force required for the dislodgement of the filling material was recorded in newtons and divided by the lateral area (SL) in mm^2 of the bonding surface. SL was calculated by the following formula: where R is the radius of the root canal in its coronal portion, r is the radius of the root canal in its apical portion, and h is the height/thickness of the slice.

Failure Mode Analysis

After the push-out test, the specimens were submitted to a careful visual examination in a stereomicroscope (SteREO Discovery V12, Carl Zeiss, Göttingen, Germany) at ×20 to ×50 magnifications. The failures modes were classified according criterious established on previous studies (15), as follows: adhesive failure (dentin surface free of sealer); cohesive failure (failure within the material, with the dentin surface covered by sealer); or mixed failure (a mixture of adhesive and cohesive modes).

Statistical Analysis

The statistical tests were performed with the aid of the GraphPad Prism 4.0 Software program (GraphPad Software, La Jolla, CA, USA). The normality of the data was verified by the Shapiro-Wilk test. Then, non-parametric ($p<0.05$) and parametric ($p>0.05$) data were statistically analyzed under a 5% significance level ($p<0.05$ was established to state a statistically significant difference).

For the non-parametric data obtained by radiographic analysis of the obturation quality, Kruskal-Wallis test was applied, complemented by Tukey, Games-Howell and Bonferroni *post-hoc* tests. Regarding the stereoscopic analysis of the obturation quality, which analyzed total filled and failure areas and presented parametric data, 2-way ANOVA test and Tukey *post-*

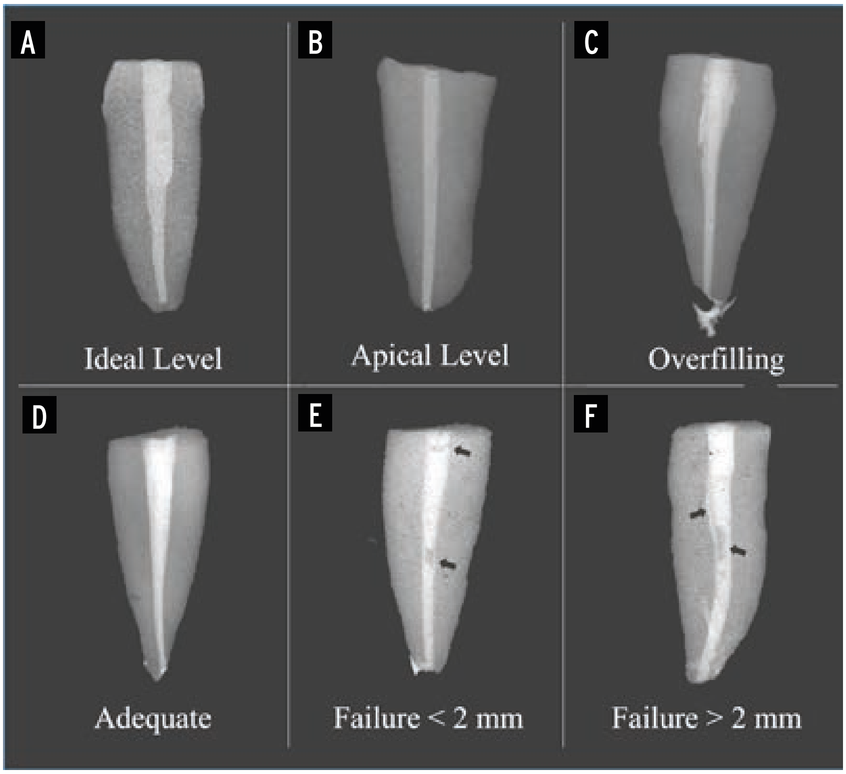

Figure 2
Representative radiographic images of the scores analyzed for the quality of the canal obturation. Regarding the level of the obturation: **(A)** Ideal level; **(B)** apical level; **(C)** overfilling. Regarding the homogeneity of the obturator mass: **(D)** adequate; **(E)** failure <2 mm; **(F)** failure >2 mm. Note the arrows pointing the regions with the failures.

hoc tests were applied. For the BS, when the different root canal thirds of each group were considered in the analysis, the data were submitted to Kruskal-Wallis test, complemented by Games-Howell *post-hoc* test. In the comparison between the groups, the statistical analysis was performed by the Kruskal-Wallis test, complemented by the Sidak *post-hoc* test.

Results

Obturation Quality

Representative radiographic images of the scores analyzed for the quality of the canal obturation are showed in the Figure 2, regarding the level of the obturation (Fig. 2A-C), and the homogeneity of the obturator mass (Fig. 2D-F). Table 1 shows the count and percentage of scores obtained in the radiographic analysis of the homogeneity of the obturator mass. There was no statistical difference amongst the root canal thirds for G_{LC}, G_{SC} and G_{TH}, except for G_{CW}, in which the middle third presented significantly difference from the others (p=0.003), with a higher number of specimens with failures <2 mm (score 2, Figure 2E). In the comparison among the groups, regardless of the thirds, a statistically significant difference was observed (p=0.005). G_{TH} and G_{CW} differed from G_{LC}, which presented higher number of failures.

The count and percentage of the scores obtained in the radiographic analysis of the filling levels are presented in Table 2. There was a statistical difference among the groups (p=0.005), in which G_{TH} showed higher number of specimens with overfilling (Figure 2C), differing statistically from G_{LC} (p=0.017) and G_{SC} (p=0.006).

Regarding stereomicroscope analysis, the mean values of the filled and the failure areas (in mm^2) for the different filling techniques were presented in Table 3. There was a statistically significant difference of the filled areas among the groups (p=0.003). G_{TH} had the largest filled area, differing statistically from the G_{LC} (p=0.001), which had the smallest filled area. As for the failure area, there was no statistically significant difference among the groups evaluated (p=0.278). However, when the failure percentages (total failure area/total filled area) were compared, it was observed that the G_{LC} group had a higher percentage of failures than the other groups.

BS and Failure Modes

The mean values (MPa) of BS obtained from push-out test, for each group considering the different root canal thirds are summarized in Table 4. It was observed that the apical third presented the highest values of BS for all groups evaluated, differing statistically from the other root thirds of each group. When comparing the thirds between the groups, in the cervical third, the G_{CW} presented the lowest BS values, differing statistically from the other groups. For the middle third, the G_{CW} showed the lowest BS values, differing statistically from G_{LC} (p=0.001) and G_{TH} (p=0.018), but not differing from G_{SC} (p=0.051). For the apical third, G_{LC} presented the highest BS values, differing statistically from the other

Table 1

Count (number of specimens) and percentage (%) of filling quality (attributed scores) for the different obturation techniques and root canal thirds.

Groups[†]	Thirds	Absence of failure (score 1)	Presence of failure <2 mm (score 2)	Presence of failure >2 mm (score 3)	*p*
G_{LC}[B]	Coronal[a]	4 (44.4%)	5 (35.7%)	1 (14.3%)	*0.324*
	Middle[a]	2 (20.0%)	4 (28.6%)	4 (57.1%)	
	Apical[a]	3 (33.3%)	5 (35.7%)	2 (28.6%)	
	Total	9 (30.0%)	14 (46.7%)	7 (23.3%)	
G_{SC}[AB]	Coronal[a]	5 (38.5%)	3 (25.0%)	2 (40.0%)	*0.367*
	Middle[a]	5 (38.5%)	5 (41.7%)	0 (0.0%)	
	Apical[a]	3 (23.1%)	4 (33.3%)	3 (60.0%)	
	Total	13 (43.3%)	12 (40.0%)	5 (16.7%)	
G_{TH}[A]	Coronal[a]	7 (33.3%)	3 (42.9%)	0 (0.0%)	*0.947*
	Middle[a]	7 (33.3%)	1 (14.3%)	2 (100.0%)	
	Apical[a]	7 (33.3%)	3 (42.9%)	0 (0.0%)	
	Total	21 (70.0%)	7 (23.3%)	2 (6.7%)	
G_{CW}[A]	Coronal[a]	7 (36.8%)	3 (33.3%)	0 (0.0%)	*0.001*
	Middle[b]	2 (10.5%)	6 (66.7%)	2 (20.0%)	
	Apical[a]	10 (52.6%)	0 (0.0%)	0 (0.0%)	
	Total	19 (63.3%)	9 (30.0%)	2 (6.7%)	

Different lowercase letters in the columns indicate that there is statistical difference among the root canal thirds (Kruskal-Wallis test, Games-Howell post-hoc test $p<0.05$).
Different uppercase letters in the columns indicate that there is statistical difference among the groups (Kruskal-Wallis test, Bonferroni post-hoc test $p<0.05$).
[†]G_{LC}, G_{SC}, G_{TH} and G_{CW} are the experimental groups according to the technique used in the root canal obturation: Lateral Compaction (G_{LC}), Single Cone (G_{SC}), Tagger's Hybrid (G_{TH}) and Continuous Wave condensation (G_{CW}).

groups. When the root canal thirds were not considered in the analysis, it was observed statistically significant difference, in which G_{CW} had the lowest BS values compared to the other groups (*p*<0.05) (Table 4). The distribution of the failure modes (adhesive, cohesive or mixed) is showed in the Table 5. G_{LC}, G_{TH} and G_{CW} presented predominantly mixed failures, while G_{SC} presented predominantly cohesive failures.

Discussion

The three-dimensional filling of the root canal system is one of the conditions for endodontic treatment to be successful in the long term (16). For this reason, the materials used during this stage should completely fill the root canal space, ideally forming a mass that contains a large volume of core material, usually gutta-percha, and a small amount of sealer to prevent microleakage of by-products and growth or new bacterial infiltration (16). In order to obtain this ideal mass, different filling techniques have been proposed and studied, despite this, until now, there is no agreement in the literature about the best obturation technique to achieve this objective and promote greater adhesion of

Table 2

Filling level count (number of specimens) and percentage (%) compared to different obturation techniques.

Groups†	Ideal	Apical	Overfilling
G_{LC} A	6 (42.9%)	3 (16.7%)	1 (12.5%)
G_{SC} A	6 (42.9%)	4 (22.2%)	0 (0.0%)
G_{TH} B	0 (0.0%)	6 (33.3%)	4 (50.0%)
G_{CW} AB	2 (14.2%)	5 (27.8%)	3 (37.5%)
Total	**14 (35.0%)**	**18 (45.0%)**	**8 (20.0%)**

Different superscript uppercase letters in the column indicate that there is statistical difference between the groups (Kruskal-Wallis test, Bonferroni post-hoc test, p<0.05).
†G_{LC}, G_{SC}, G_{TH} and G_{CW} are the experimental groups according to the technique used in the root canal obturation: Lateral Compaction (G_{LC}), Single Cone (G_{SC}), Tagger's Hybrid (G_{TH}) and Continuous Wave condensation (G_{CW}).

Table 3

Mean values and standard deviation of the total filled and failure areas (mm^2) compared to the different obturation techniques.

Groups†	Filled Area (mm^2)	Failure Area (mm^2)	Failure Percentage
G_{LC}	2.44 ± 0.94^{B}	0.098 ± 0.09^{A}	4.00%
G_{SC}	3.28 ± 1.75^{AB}	0.038 ± 0.05^{A}	1.15%
G_{TH}	4.77 ± 1.38^{A}	0.083 ± 0.07^{A}	1.73%
G_{CW}	3.40 ± 0.81^{AB}	0.073 ± 0.08^{A}	2.03%

Different superscript letters in the columns indicate that there is statistical difference between the filling techniques (2-way ANOVA test and Tukey's post-hoc test, p<0.05).
†G_{LC}, G_{SC}, G_{TH} and G_{CW} are the experimental groups according to the technique used in the root canal obturation: Lateral Compaction (G_{LC}), Single Cone (G_{SC}), Tagger's Hybrid (G_{TH}) and Continuous Wave condensation (G_{CW}).

the filling material to the root canal walls (17, 18). Therefore, the present study evaluated the influence of different obturation techniques on the radiographic quality and BS of the filling material to the root canal dentin. According to the results of the present study, the null hypothesis was rejected, as the different obturation techniques influenced the radiographic quality and the BS of the filling material to the root canal walls. Such results corroborate with several studies that have reported the effect of the obturation techniques on the BS of the filling material to the root canal dentin (4, 6, 14, 19).

In the present study, the quality of the root canal obturation was assessed using periapical radiographs taken in the mesio-distal and buccal-lingual direction (10). In this analysis, we tried to observe failures in the filled root canals. The quality of the root canal obturation has been associated with a radiographic image with homogeneous, free-space and compact filling material (16). The G_{TH} had the least number of failures in the interface between the filling material and the root canal walls, showing superiority in relation to the other obturation techniques. The G_{LC}, on the other hand, was the group that presented the largest number of specimens with empty spaces in the obturated root canal. Although some studies have been concluded that the quality of the obturation achieved with the lateral compaction is similar to other techniques (20), our findings corroborate with others that demonstrated better results with the Tagger's

Table 4

Bond strength means values (MPa) and standard deviations for the experimental groups and root canal regions after push-out tests.

Groups[†]	Coronal	Middle	Apical	All Root Thirds
G_{LC}	3.61 ± 2.03^{Ab}	5.58 ± 2.48^{Ab}	11.60 ± 3.43^{Aa}	6.93 ± 4.33^{A}
G_{SC}	3.60 ± 1.42^{Ab}	4.53 ± 1.57^{Ab}	6.74 ± 2.32^{Ba}	4.96 ± 2.21^{A}
G_{TH}	4.60 ± 1.14^{Ab}	4.84 ± 1.13^{Ab}	7.57 ± 3.58^{Ba}	5.67 ± 2.58^{A}
G_{CW}	0.97 ± 0.47^{Bb}	2.20 ± 0.78^{Bb}	5.64 ± 1.37^{Ba}	2.94 ± 2.21^{B}

Different superscript lowercase letters in the lines indicate statistical difference among the root thirds (Kruskal-Wallis test, Games-Howell post-hoc test, $p<0.05$).
Different superscript uppercase letters in the columns indicate statistical difference among the filling protocols (Kruskal-Wallis test, Sidak post-hoc test, $p<0.05$).
[†] *G_{LC}, G_{SC}, G_{TH} and G_{CW} are the experimental groups according to the technique used in the root canal obturation: Lateral Compaction (G_{LC}), Single Cone (G_{SC}), Tagger's Hybrid (G_{TH}) and Continuous Wave condensation (G_{CW}).*

Table 5

Distribution of failure modes (%) in the specimens of the experimental groups after push-out tests.

Groups[†]	Adhesive	Cohesive	Mixed
G_{LC}	18.93	37.83	43.24
G_{SC}	20.94	53.48	25.58
G_{TH}	20.00	35.55	44.45
G_{CW}	23.25	18.61	58.14

[†] *G_{LC}, G_{SC}, G_{TH} and G_{CW} are the experimental groups according to the technique used in the root canal obturation: Lateral Compaction (G_{LC}), Single Cone (G_{SC}), Tagger's Hybrid (G_{TH}), and Continuous Wave condensation (G_{CW}).*

hybrid technique (13). Regarding the analysis of the filling material level, it was possible to verify a significant difference between these two groups, in which the root canals filled by the Tagger's hybrid technique presented a greater number of overfilling.
Other studies observed the presence of overfilling, when comparing two different obturation techniques, a thermoplasticized gutta-percha technique and the lateral compaction (7). The specimens were analyzed visually and under stereomicroscope. The heated gutta-percha group had a higher number of overfilling; however, it obtained a better flow and gutta-percha adaptation, filling consequently the irregularities of the root canal wall. These results corroborate with the present study, in which G_{TH} and G_{CW} showed the highest amount of overfilling, despite the first presented larger filling area when comparing with G_{LC}.
There was a significant difference among the experimental groups, when was evaluated the mean area (in mm^2) filled in each dentin slice, and the percentage of empty spaces in relation to these areas. The G_{TH} and the G_{LC} had a larger and a smaller filling area, respectively. Previous study evaluated the percentage of the root canal area filled by gutta-percha, and demonstrated that the lateral compaction technique had 93.8% of gutta-percha filling the canal space, differing statistically from the heated gutta-percha techniques, which presented 96.9% of the root canal filled by gutta-percha (8). However, there was over-

filling in all specimens in the heated gutta-percha group. In other study, it was determined the percentage of gutta-percha area at the apical third of root canals obturated by two different techniques, Thermafil and lateral compaction (9). The specimens were analyzed under stereomicroscope and it was possible to determine the total area of the root canal, the areas filled by gutta-percha and the areas of the empty spaces. The group obturated by the lateral compaction technique had a higher percentage of failures than the other group. It is important to note that in the lateral compaction technique there is no effective filling of the irregularities of the root canal walls; whereas, in the thermoplasticized gutta-percha techniques promote a better flow of the filling material, ensuring a proper filling of possible irregularities of the root canal (7, 10).

When comparing the influence of the obturation technique on the BS of the filling material along the root canal thirds, it was observed that regardless of the obturation technique performed, the highest BS values were obtained at the apical third. In a similar study, it was concluded that the BS is affected by the shape/region of the root canal, and a higher percentage of the canal area filled with gutta-percha, instead of the sealer, results in higher BS values of the filling material to root dentin (21). Therefore, in the present study, this fact may be related to the higher BS obtained at the apical third, as during the filling procedure, this was the root canal portion where the master cone was adapted to the root canal and, consequently, a greater percentage of the canal area is filled by gutta-percha in relation to sealer.

The literature has shown that the lateral compaction technique produces many irregularities in the final gutta-percha mass and a poor dispersion of the sealer through the root canal, resulting in gaps that, when present, may act as failure initiating sites during the push-out test, reducing the BS values (4). In the present study, the lateral compaction technique group showed a higher percentage of failure in both methods of analysis. Despite that, for the apical third of the canal, this technique showed a greater adhesive potential. This may be related to the fact that during the execution of this technique, it is necessary to use a finger spreader to create space for the insertion of accessory cones, which results in significant compaction pressure on the sealer. According to previous study, the application of pressure results in greater contact between the dentin and the filling material, resulting in higher BS values (22).

In the present study, the continuous wave technique had the lowest BS values, differing statistically from the other groups. When considering the root thirds in the analysis, the cervical and middle thirds of this group also showed lower values. As already noted, gaps and failures decrease the BS between the filling material and the root dentin (4). It may be assumed that during the downpacking stage - in which the filling material present at the middle and apical thirds of the canal is removed - and later filling with an injection gun, there is a greater susceptibility for gaps and failures to occur (23).

AH Plus sealer has a greater BS to dentin than to gutta-percha (24). This fact may be related to the higher percentage of cohesive type failures in the samples filled by the single-cone filling technique, present in this study at G_{SC}, since during the execution of this technique, no other physical action is performed - such as compaction or thermoplasticization - in gutta-percha and the adhesion of the filling material can be restricted only to the endodontic sealer used. In addition, this fact may also be related to the higher percentage of mixed failures in the other groups (G_{LC}, G_{TH} and G_{CW}), because despite the plastification or compacting of the gutta-percha during the obturation procedure, when submitted to the push-out test, the samples still presented the dentin surface covered with sealer.

Although microscopic evaluations of root sections are frequently used in other studies (8, 10, 11), this methodology has some limitations and precautions that must be observed. The absence of intense refrigeration during specimen cutting can cause softening of the filling material and compromise the evaluation of existing flaws within the material, or at its interface with the dentin (10). The push-out test also has some limitations that should be taken into consideration when interpreting the results. Preparing push-out test samples can be time-consuming and requires careful attention to detail to avoid variations in BS (15). During the test, the interface between the filling material and dentin may be subjected to localized stress concentrations, which can complicate the interpretation of the results (25). Finally, in the present study, the push-out test was conducted under ambient conditions, which may not accurately represent the way in which the materials are used in a clinical situation. However, the push-out test is considered a reliable method for evaluating the BS to root dentin by allowing the force to be applied parallel to the adhesive interface, besides enabling the determination of the BS in the different root canal thirds (15, 19, 21, 24). Furthermore, the push-out test is suitable for ranking the BS of filling materials to root canal dentin even with conventional core materials (26).

Despite some studies demonstrate that there is no relationship between the technique performed and the adhesion of the filling material to the root canal walls (27), and other studies reinforce the capacity of the thermoplasticized gutta-percha to adapt and to fill the canal space without using sealer (11), in the present study, the different obturation techniques influenced the BS of the filling material to the root dentin.

Given this, there is a need for further studies comparing different filling techniques, using different sealers and different methodologies, in order to determine the technique that results in a greater quality and BS of the filling material to the root dentin and, consequently, in a greater longevity of endodontic treatment performed.

Conclusion

The different obturation techniques of the root canal influenced the quality and BS of the filling material to the root dentin. Tagger's hybrid technique showed the best filling quality, with a larger filling area, however it presented a greater amount of overfilling. The lateral compaction technique showed a higher percentage of failure in both methods of analysis, despite that, for the apical third of the canal, showed greater adhesive potential. The continuous wave condensation technique provided less adhesion between the filling material and the root canal dentin.

Clinical Relevance

The findings of our study demonstrated that different obturation techniques can provide distinct results regarding adhesion to root canal dentin and filling quality of the obturation material. Endodontists need to be aware of these variations in order to apply the most appropriate obturation technique that leads to better clinical results.

Conflict of Interest

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

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ORIGINAL ARTICLE

Relationship between inflammation site and apical periodontitis in patients with severe endodontic pain

Tuna Kaplan

Sema Sönmez Kaplan*

Güzide Pelin Sezgin

Department of Endodontics, Faculty of Dentisrty, University of Biruni, Istanbul, Turkey.

ABSTRACT

Aim: *To assess the relationship between inflammation site and apical periodontitis in patients with severe endodontic pain on periapical radiographs using a periapical index (PAI) scoring system.*

Methodology: *This was a retrospective study of patients who visited the Department of Endodontics, Faculty of Dentistry, X University between January 2020 and December 2021 with the complaint of severe endodontic pain. After application of specific exclusion criteria, 985 patients with severe endodontic pain were included. Inflammation in the patient population was classified as follows: a positive response to the electric pulp test (stage 1), a negative response to the electric pulp test without swelling (stage 2) or a negative response to the electric pulp test with swelling (stage 3). Using the PAI scoring system, periapical status was then classified as healthy (PAI: 1 or 2) or unhealthy (PAI: 3, 4 or 5). The level of significance was set at 5%* ($p<0.05$)*.*

Results: *The lowest severity of apical periodontitis (AP) was found in patients with a positive response to the electric pulp test (stage 1)* ($p<0.05$)*. Among cases with a negative response to the electric pulp test, the incidence of AP was significantly higher in patients with swelling than in those without swelling* ($p<0.05$)*.*

Conclusions: *The present study detected a relationship between the main site of inflammation and AP in patients with severe endodontic pain. The presence or absence of AP might serve as a useful indicator in patients with severe endotontic pain.*

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Corresponding Author
Sema Sönmez Kaplan DDS, PhD | Biruni University, Faculty of Dentistry, Department of Endodontics, Istanbul | Turkey
Phone number: (+90) 212 415 14 14, (+90) 537 262 44 27 Email: semak@biruni.edu.tr

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Introduction

A proper endodontic diagnosis is essential to guide appropriate treatment. In the past, histological, clinical and radiographic findings were used to guide the diagnosis. However, the relationship between these findings and tooth status was not always clear (1, 2). In recent years, to improve the endodontic diagnostic approach and overcome diagnostic difficulties due to dilemmas, dental anamnesis and clinical and radiographic evidence have been used (3, 4). As endodontic infections arise in the pulpal space and then spread to the periapex (5), endodontic diagnosis depends on pulp vitality, percussion sensitivity and palpation tests, which are used to determine the status of periapical tissues (3). The endodontic diagnosis is relatively uncomplicated in patients who present with severe pain or spontaneous pain. However, the histological and clinical evidence may be inconclusive in patients who present without pain (6-8).

Thus far, no studies have investigated periapical radiographic findings in endodontic patients with severe pain. From a clinical perspective, this might appear insignificant, as root canal treatment is indicated in such conditions, whether bone resorption is detected on a periapical radiograph or not. However, it is important to clarify this relationship to identify the source of pain and origin of endodontic infection. Due to the way in which teeth and surrounding tissue is encoded by the sensory nervous system, inflammation of various structures (i.e., pulp, periodontal ligament, or periosteum) can cause pain (9).

Periapical radiographs are routinely used to examine healing progress in endodontically treated teeth using a periapical index (PAI) scoring system (10). This scoring system was developed based on histological and radiographic examinations of teeth in human cadavers (11, 12). Using the PAI scoring system, inflammation is assessed on a scale of 1-5, where 1 denotes no inflammation and 5 denotes severe inflammation. As the PAI scoring system is based on cadaver studies, whether the examined teeth were symptomatic or not at the moment of death is unclear. In addition, these studies did not address superimposition related to posterior teeth. An additional weakness of the PAI scoring system is its dependence on visible evidence from images of inflammation stages as they appear on periapical radiographs (11-13).

In the last decade, the use of cone-beam computed tomography (CBCT) in endodontic diagnosis has increased. However, CBCT is not routinely used to aid endodontic diagnoses due to its high radiation dose (14, 15). Furthermore, previous research demonstrated that periapical inflammation identified by CBCT may be temporary, even in cases of a high level of inflammation (16). In addition, a study focusing on RANKL/osteoprotegerin and interleukin-8 in pulpal and periapical pathology pointed out that bone resorption takes precedence over inflammation (17). On the other hand, such differences related to highly inflamed pulps were not investigated on periapical radiographs, although the opinion that small periapical lesions cannot be identified in posterior teeth has been disputed (18-20).

Given the importance of periapical radiographs in endodontic diagnosis, it is important that they shed light on bone inflammation. Unexpectedly, there seems to be an absence of information correlating severe pain and inflammation in endodontic patients based on periapical radiographs. Thus, the aim of the present study was to correlate inflammation (stage) with periapical status (healthy or unhealthy) in patients who presented to our department with severe endodontic pain using periapical radiographs and the PAI index.

Materials and Methods

Study design

The present study was approved by the ethics committee of X University (2022/66-17) and performed in accordance with the Declaration of Helsinki. The records of patients who visited the Department of

Endodontics, Faculty of dentistry, X University between January 2020 and December 2021 with severe endodontic pain were examined retrospectively. At the time of presentation, the patients were questioned about primary problems and symptoms. All the patients then underwent a complete endodontic evaluation by the endodontist on duty at the time. The examiners who performed during the evaluation had been calibrated.

Exclusion criteria
The exclusion criteria included pregnancy, immunosuppressive drug taking, long-term use of anti-inflammatory drugs and antibiotics use over the previous month. In addition, to ensure that only patients with severe pain of endodontic origin were included, all patients with a Visual Analogue Scale (VAS) score of <7 were excluded. Additional exclusion criteria were commencement of endodontic treatment for the patient's complaint at another institution or failure to make an accurate diagnosis. Finally, periapical radiographs with artefacts and of poor quality were excluded.

Clinical and radiographic assessment
The patients scored the highest pain level experienced in the previous 24 hours on the VAS, where a VAS score of 0 denoted "no pain" and a score of 10 denoted "the worst pain imaginable" (21). The patients were also asked about the pain duration of the affected teeth, including whether they had experienced spontaneous pain for more than 1 week. Inspection of the affected tooth and surrounding tissues, an electric pulp test and a percussion sensitivity test were performed for clinical examination. The affected tooth was compared to the contralateral tooth, which was free of pain and swelling. The dental history of each patient was documented in a chart. Periapical radiographs were taken using a phosphor plate radiography system (Dürr Dental, Bietigheim-Bissingen, Germany) with a film holder, using the parallel technique for standardization.
In the retrospective evaluation, one experienced endodontist assessed the radiographs using Picture Archiving and Communication Systems software version (1.1.1.6) for Windows 10 (Microsoft Corporation, Redmont, WA, U.S.A.), with the images displayed on a 28-inch Samsung LU28H750UQMXUF (Samsung Electronics, Seoul, South Korea) at a 3,840×2,160 pixel resolution.

Data collection
Patient age and sex, pain duration (<1 week and >1 week), sensitivity to percussion, location (maxilla or mandible), tooth type (incisor, canine, premolar, or molar), presence and type of restoration (composite, amalgam, crown, or bridge abutment), presence of root canal filling, response to the pulp vitality test (positive or negative) and presence of swelling were recorded in a specially designed form.

Assessment of periapical status
Periapical status was assessed radiographically using the 5-point scale of the PAI scoring system to determine the presence of periapical pathology (12). For calibration, two endodontists with at least 5 years of experience examined 50 periapical radiographs. Disagreement between the examiners was resolved through discussion until consensus was reached. The calibration was performed twice, with a 1-week interval. Intra- and interexaminer consensus were then calculated using Cohen's kappa coefficient. For intraexaminer consensus, the values were 0.79 and 0.76, and the value for interexaminer consensus was 0.71, suggesting substantial agreement (22). Both endodontists then assessed the periapical radiographs under standard conditions. In cases of uncertainty, the higher PAI score was selected. For multirooted teeth, the highest PAI score assigned to individual roots was used. During the evaluation, the examiners were blinded to both patient- and tooth-related information.

Statistical analysis
For statistical analysis, inflammation was classified as positive response to the electric pulp test (stage 1), negative response

to the electric pulp test without swelling (stage 2) or negative response to the electric pulp test with swelling (stage 3), and periapical status (healthy=PAI of 1 or 2; unhealthy=PAI of 3, 4 or 5). IBM SPSS Statistics for Windows, version 22 (IBM Corp., Armonk, NY, U.S.A.) was used for statistical analysis of the findings. A chi-square test was used to compare qualitative data. Descriptive data are presented as mean, standard deviation and frequency. The level of significance was set at 5% ($p < 0.05$).

Results

Demographic data
Between January 2020 and December 2021, 2,051 patients visited the Department of Endodontics, Faculty of Dentistry, X University with severe endodontic pain. After elimination of patients according to the exclusion criteria, 985 patients were included in the study. The mean age of the patients was 32.9±12.8 years. The male:female ratio was 40.9:59.1%.

Evaluation of clinical status
The incidence of stage 2 inflammation was significantly higher than stage 1 or 3 inflammation. In addition, the incidence of stage 1 was significantly higher than stage 3 (Table 1).
In terms of pain history, it was significantly longer in the stage 1 group than stage 2 and stage 3 groups ($p<0.05$). Percussion sensitivity was significantly lower in the stage 1 group as compared with that in the other groups ($p<0.05$). The percentage of incisors and restored teeth was significantly lower in the stage 1 group as compared with that in the other groups ($p<0.05$). The percentage of canines in the stage 3 group was significantly higher than that in the other groups ($p<0.05$), whereas the percentage of molars in the stage 1 group was significantly higher compared to that in the other groups ($p<0.05$). In the stage 3 group, the incidence of endodontically treated teeth was significantly higher in comparison with that in the stage 2 group ($p<0.05$) (Table 2).

Correlation between clinical status and AP
A correlation was detected between the main site of inflammation and pain severity. In this study, a PAI score of 3 or higher denoted AP. The incidence of AP was lowest in the stage 1 group (pulpal inflammation) ($p<0.05$). The incidence of AP was significantly higher in the stage 3 group than that in the stage 2 group ($p<0.05$) (Table 2).

Further evaluation of AP
Neither age nor sex was statistically significantly associated with the presence of AP. The incidence of AP was significantly higher in patients with pain histories of more than 1 week and sensitivity to percussion ($p<0.05$). Teeth located in the mandible also had higher percentages of AP ($p<0.05$). Furthermore, incisors showed a statistically higher presence of AP than other tooth types ($p<0.05$). The incidence of AP in endodontically treated teeth in the stage 3 group was significantly higher than that in the stage 2 group ($p<0.05$) (Table 3).

Discussion

The present study on patients who presented to our department with severe endodontic pain showed that inflammation was correlated with AP based on a retrospective evaluation of periapical radiographs, PAI scores and clinical status.
PAI scores projected the process of inflammation from the pulp to the periodontal ligament and later periapex. Furthermore, PAI scores of the teeth were not significantly affected by anatomical structures. In addition, most of the patients with negative responses to the electric pulp test who had severe endodontic pain did not show evi-

Table 1
Evaluation of clinical status

	Subject	
	n	%
Stage 1	381	38.7
Stage 2	526	53.4
Stage 3	78	7.9
p	0.000*	

One sample chi-square test **p<0.05*

Table 2
Evaluations of case groups

		Stage 1 n (%)	Stage 2 n (%)	Stage 3 n (%)	p
Age	13-19	89 (23.4)	102 (19.4)	22 (28.2)	0.002*
	20-29	88 (23.1)	112 (21.3)	16 (20.5)	
	30-39	111 (29.1)	138 (26.2)	12 (15.4)	
	40-49	69 (18.1)	100 (19)	14 (17.9)	
	50-59	17 (4.5)	37 (7)	10 (12.8)	
	60+	7 (1.8)	37 (7)	4 (5.1)	
Sex	Male	162 (42.5)	215 (40.9)	26 (33.3)	0.323
	Female	219 (57.5)	311 (59.1)	52 (66.7)	
Duration of pain	<1 week	110 (28.9)	298 (56.7)	53 (67.9)	0.000*
	>1 week	271 (71.1)	228 (43.3)	25 (32.1)	
Percussion sensitivity	Absent	99 (26)	100 (19)	9 (11.5)	0.004*
	Present	282 (74)	426 (81)	69 (88.5)	
Jaw	Maxilla	186 (48.8)	274 (52.1)	37 (47.4)	0.534
	Mandible	195 (51.2)	252 (47.9)	41 (52.6)	
Tooth type	Incisor	11 (2.9)	41 (7.8)	9 (11.5)	0.000*
	Canine	12 (3.1)	20 (3.8)	7 (9)	
	Premolar	75 (19.7)	107 (20.3)	23 (29.5)	
	Molar	283 (74.3)	358 (68.1)	39 (50)	
Restoration	None	273 (71.7)	250 (47.5)	33 (42.3)	0.000*
	Composite	68 (17.8)	131 (24.9)	27 (34.6)	
	Amalgam	40 (10.5)	102 (19.4)	9 (11.5)	
	Crown	0 (0)	16 (3)	2 (2.6)	
	Bridge abutment	0 (0)	27 (5.1)	7 (9)	
Root canal filling	Absent	381 (100)	423 (80.4)	51 (65.4)	0.000*
	Present	0 (0)	103 (19.6)	27 (34.6)	
AP	Absent	368 (96.6)	338 (64.3)	10 (12.8)	0.000*
	Present	13 (3.4)	188 (35.7)	68 (87.2)	

*Chi-square test *p<0.05*

dence of AP at the time of the evaluation.
Despite a lack of certainty in endodontic diagnosis in patients presenting with tooth pain, inflammation can be classified as follows: stage 1, severely painful inflammation of the pulp; stage 2, severe tooth pain with necrotizing or necrotic pulp; and stage 3, severe periapical pain with swelling. The decision to perform root canal treatment is based on both a clinical and radiographic examination.
Considering the routine use of digital periapical radiography, it is surprising that there have been no systematic studies of periapical radiographic images obtained from patients with severe endodontic pain. The present study aimed to shed light on this subject. No histological or CBCT examination results exist to confirm our findings. As this was a retrospective study, a histological examination was not practicable. Furthermore, to prevent unnecessary exposure to radiation, CBCT was not performed in cases of severe endodontic pain where the cause of the pain could be clearly diagnosed
In accordance with similar studies in the literature (23, 24), the incidence of a negative response to the vitality test was significantly higher in patients than in those with a positive response to the vitality test. The patients in the present study were selected from those who attended a university hospital. The socioeconomic status of the patients who attend such hospitals, which provide free or low-cost care, tends to be relatively low, and the patients tend to neglect dental care needs. The aforementioned may explain the high incidence of necrotic pulp cases in the present study. Rechenberg et al. found that teeth in stage 1 group were less restored (24). In this study, the restored teeth in this case group were significantly lower than in the other groups.
This finding is also likely due to neglect of dental care, with the patients not consulting a dental practitioner until they experienced severe pain. Failure to seek prompt tooth restoration treatment for primary caries lesions led to severe inflammation and pain. A comprehensive systematic review of the literature may clarify and aid clinicians in

Table 3

Evaluations regarding the presence of AP

		Without AP n (%)	With AP n (%)	p
Age	13-19	152 (71.4)	61 (28.6)	0.095
	20-29	158 (73.1)	58 (26.9)	
	30-39	201 (77)	60 (23)	
	40-49	135 (73.8)	48 (26.2)	
	50-59	38 (59.4)	26 (40.6)	
	60+	32 (66.7)	16 (33.3)	
Sex	Male	285 (70.7)	118 (29.3)	0.248
	Female	431 (74.1)	151 (25.9)	
Duration of pain	<1 week	298 (64.6)	163 (35.4)	0.000*
	>1 week	418 (79.8)	106 (20.2)	
Percussion sensitivity	Absent	164 (78.8)	44 (21.2)	0.025*
	Present	552 (71)	225 (29)	
Jaw	Maxilla	377 (75.9)	120 (24.1)	0.024*
	Mandible	339 (69.5)	149 (30.5)	
Tooth type	Incisor	33 (54.1)	28 (45.9)	0.000*
	Canine	25 (64.1)	14 (35.9)	
	Premolar	140 (68.3)	65 (31.7)	
	Molar	518 (76.2)	162 (23.8)	
Restoration (n=429)	Composite	136 (60.2)	90 (39.8)	0.108
	Amalgam	107 (70.9)	44 (29.1)	
	Crown	9 (50)	9 (50)	
	Bridge abutment	21 (61.8)	13 (38.2)	
Root canal filling (n=604)	Absent	672 (78.6)	183 (21.4)	0.000*
	Present	44 (33.8)	86 (66.2)	

Chi-sqare test *p<0.05

performing an optimal root canal treatment (25). On the other hand, pain may be considered as a pre-operative diagnostic criterion as well as a treatment success parameter (26). In the present study, the percentage of patients in the stage 1 group with a pain history of more than 1 week was significantly higher than that in the other groups. Rechenberg et al. presented a similar result (24). This finding can be explained by inflammation not yet reaching the periapical tissues. Thus, a pain history of 1 week or longer may be seen in patients with stage 1 inflammation.

Pulpal inflammation may give rise to severe pain, emergency visits to dental clinics and systemic symptoms (23, 24, 27). The diagnoses in the present cases were uncomplicated, with progression of pulpal inflammation, as demonstrated by a positive response to the electric pulp test, to inflammation affecting the periodontium and then periapical tissue. Many of the patients in the present study showed tenderness to percussion. Based on the terminology of the American Association of Endodontists, the endodontic diagnosis in these cases may have been symptomatic AP.

In this context, it is natural that the percentage of percussion sensitivity was significantly lower in the group with a positive response in the electric pulp test than that in the other groups and significantly higher when AP was present compared to when AP was absent.

In the present study, AP more commonly affected the mandible than maxilla. Among tooth types, molars were least affected by AP. In contrast, Rechenberg et al. found no significant difference in AP according to tooth type (24). Differences in the study population, dental care habits and assessment methods may explain the discord between the results of the two studies.

Of note, in this study, 38.6% of patients with a negative response to the electric pulp test showed no signs of AP (PAI score <3). The most probable reason for this finding is lesion dynamics. In addition, most of the patients with a negative response to the electric pulp test in the present study declared that the pain duration was less than 1 week. The presence of AP may explain the pain duration in these patients.

In the present study, the periapical radiographic images showed the primary site of inflammation in patients with severe endodontic pain. In most cases, inflammation and severe pain showed rapid onset, with no history of periapical lesions. In our study, the incidence of endodontically treated teeth and that of AP were low. This finding is in line with that of studies reporting that severe pain in the presence of persistent AP is rare (24, 28).

On the other hand, Rechenberg et al. reported a relatively high incidence of AP in

endodontically treated (root-filled) teeth, as reflected by higher PAI scores (24).
Similarly, the presence of AP was more common among endodontically treated teeth in this study.
Factors that can lead to AP include untreated root canals, inadequate root canal obturation and iatrogenic procedural errors. An endodontic infection, whether symptomatic or asymptomatic, is affected by the number and virulence of microorganisms and the state of the immune system (29).
Rechenberg et al. reported that periapical inflammation accompanied by severe pain may be associated with the volume of root canal accessible to microorganisms (24). This may explain why the percentage of endodontically treated teeth was low in the present study. However, it should be acknowledged that the cause of severe endodontic pain remains unexplained in most cases. Further studies are needed to shed light on this subject, as it is a significant part of clinical endodontics.

Conclusions

The present study detected a relationship between the main site of inflammation and AP in patients with severe endodontic pain. As compared with patients with a negative response to the electric pulp test, those with a positive response to the electric pulp test were characterized by a pain history of more than 1 week, less percussion sensitivity, less number of dental restorations and less presence of AP. AP was associated with a pain history of less than 1 week, percussion sensitivity, mandibles, endodontic treatment and a negative response to the electric pulp test.
Considering these findings, the presence or absence of AP might be a useful indicator of endodontic diagnosis in patients with severe endodontic pain.

Clinical Relevance

To provide information about the relationship between the inflammation and the periapical status, as it is an important part of endodontics and as there is an absence of information correlating severe pain and inflammation in endodontic patients based on periapical radiographs.

Acknowlegments

No financial support was received for this study.

Conflict of Interest

The authors declare no conflict of interest.

Ethical approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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ORIGINAL ARTICLE

A bibliometric analysis of current trends, hotspots, and future aspects of endodontic-periodontal lesions

Sıla Nur Usta[1*]

Zeliha Uğur-Aydın[1]

Mustafa Gündoğar[2]

[1]Department of Endodontics, Gulhane Faculty of Dentistry, University of Health Sciences, Ankara, Turkey.

[2]Department of Endodontics, Faculty of Dentistry, University of Medipol, Istanbul, Turkey.

ABSTRACT

Aim: *This study aims to examine the present findings, contemporary developments, and productivity of endodontic-periodontal (endo-perio) lesions based on the top 50 most-cited articles between 1990 and 2022.*

Methodology: *An electronic search was carried out in the "Clarivate Analytics Web of Science, All Databases". After ranking the articles in descending order based on their citation counts, the first 50 relevant articles were selected. Parameters such as citation density, publication year, journal, country, institution, author, study design, evidence level, and keywords were analyzed. Spearman's correlation was used to determine associations between the number of citations and citation density.*

Results: *There was a significant positive correlation between citation number and the age of publication ($p<0.05$). Articles were mostly published between 2011 and 2022. The Journal of Endodontics had the largest number of publications. The United States and The University of Southern California made the highest contribution. The majority of the articles were case reports. Ilan Rotstein, Se-Lim Oh, and Maryam Pourhajibagher were the most frequent first authors. Studies were frequently designed as case reports with evidence level V. "Endo-perio lesions" followed by "guided tissue regeneration" were mostly-used keywords.*

Conclusion: *Regenerative procedures along with endodontic treatments have been utilized in the last decade to manage endo-perio lesions due to the developments in materials and techniques. Case reports could guide dental practitioners by demonstrating updated information in this field.*

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Corresponding Author
Sila Nur Usta | Department of Endodontics, Gulhane Faculty of Dentistry, University of Health Sciences, Ankara, Turkey.
Phone: 90-507-2795558 Email: silandeniz29@gmail.com

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Introduction

The relationships between dental pulp and periodontium occur through anatomic, vascular, and pathological connections such as the apical foramina, lateral and accessory canals, exposed dentinal tubules, palatal grooves, root canal perforations, and root fractures (1). These pathways simultaneously affect the periodontal and pulpal tissues by forming endodontic and periodontal (endo-perio) lesions (2). Endo-perio lesions were classified by Simon et al. (3) as follows: "primary endodontic lesions, primary endodontic lesions with secondary periodontal involvement, primary periodontal lesions, primary periodontal lesions with secondary endodontic involvement, and true combined lesions." Since these diseases can mimic others' clinical features (4), diagnosing the endo-perio lesions as of pulpal or periodontal origin can be challenging, and it requires more profound knowledge and perspective in the field (2).
The success of the treatment of endo-perio lesions depends on assessing endodontic and periodontal contribution correctly to utilize the best treatment option (4). The lesions that mainly originate from pulpal pathosis usually heal after properly cleaning, shaping, and obturation procedures of the root canal system (5, 6). Intracanal medicaments can be preferred to enhance antibacterial activity and thus prevent the transfer of microorganisms in the root canal system to the periodontium (5). Additionally, contemporary irrigation activation systems and antibacterial materials such as lasers (7), automated root canal irrigation systems (8), silver nanoparticles (9), and natural extracts (10) can be utilized as treatment approaches in order to improve disinfection. If a lesion of endodontic origin is untreated, it damages the hard and soft tissues in the periapical area, leading to the involvement of periodontal disease (11). A better outcome in such cases requires applying adequate periodontal therapy followed by endodontic treatment (12). Furthermore, combined lesions that pulpal and periodontal disease may occur individually or simultaneously are needed to be treated with periodontal treatment followed by endodontic treatment (13).
Treating endo-perio lesions may pose a challenge, especially when the existence of an excessive loss of periodontal attachment and bone structure (14). In this sense, conventional endodontic and periodontal treatments may be insufficient, and resection or regenerative approaches may be required (15). Several contemporary treatment methods have been recently developed to advance microbial activity and regenerate periodontal tissues, such as guided tissue regeneration with barrier membranes, grafting materials, enamel matrix proteins, and autologous platelet concentrates (16, 17).
The bibliometric analysis aims to statistically evaluate publications within a field of interest by examining the quality of articles and journals, collaboration between authors or institutions, and new trends in the research context (18, 19). Citation analysis, the most frequently used metric, can partially provide the scientific value of publications, reflect the past, current, and future research trends, and guide the researchers to follow developments in particular fields (20, 21). As well as in other specialties in the dentistry field (22, 23), several bibliometric analyses have also been conducted to address specific topics in endodontics (24, 25).
Although many studies in the literature investigate the aetiology, diagnosis, classification, and treatment of endo-perio lesions, these lesions are still a dilemma for clinicians. Due to the rapid growth rate in the development of the materials and techniques used in treating endo-perio lesions, it has become important to evaluate the scientific impact of such studies on research and clinical applications.
To our knowledge, the most cited articles have not been identified to date in this field. Therefore, this study aims to examine the current knowledge, innovations, and productivity of endo-perio lesions based on the top 50 most-cited articles from 1990 to 2022.

Materials and Methods

This bibliometric analysis was performed to determine the articles about the management of endo-perio lesions with the highest citation counts from 01.01.1990 to 01.01.2022. Clarivate Analytics Web of Science (WoS) (http://www.webofknowledge.com) was accessed to search and determine the most cited articles about endo-perio lesions in all databases since WoS contains peer-reviewed, high-quality scientific journals published worldwide (26). Two researchers (SNU and ZUA) with experience in endodontics and/or bibliometrics designed the search strategy. An extensive search was utilized using frequently utilized keywords related to the topic. No restriction was applied during the search process. Firstly, the below-mentioned three search groups were created on 1 May 2022 and articles were obtained:

1. Q1: (((((((ALL=(endod*)) OR ALL=(dental pulp necrosis)) OR ALL=(pulp necrosis)) OR ALL=(endodontic inflammation)) OR ALL=(nonvital teeth)) OR ALL=(nonvital tooth)) OR ALL=(endodontic infection*)) OR ALL=(pulpal disease). 3479 articles were received.
2. Q2: (((((((ALL=(periodont*)) OR ALL=(adult periodontitis)) OR ALL=(chronic periodontitis)) OR ALL=(aggressive periodontitis)) OR ALL=(periodontal pocket)) OR ALL=(apical periodontitis)) OR ALL=(periodontal infection*)) OR ALL=(periodontal disease). 102922 articles were received.
3. Q3: (((((((ALL=(endo-perio lesion*)) OR ALL=(endodontic periodontal lesion*)) OR ALL=(combined lesion*)) OR ALL=(periapical lesion*)) OR ALL=(treatment*)) OR ALL=(therapy)) OR ALL=(surgery)) OR ALL=(management*). 12352168 articles were received.

These three main groups were combined as [(Q1 AND Q2) AND Q3], and 7894 articles were obtained in total. Afterwards, the articles were downloaded for bibliometric analysis and listed in descending order of their citation counts. If more than one article received the same number of citations, the article with the higher citation density was listed higher (21). Two independent researchers (SNU and ZUA) examined and characterized the articles to determine whether the main focus was endo-perio lesions. Any disagreements were resolved by consulting with the third researcher (MG) until a consensus was reached.

The citation count, citation density, publication year, journal, country, institution, first author, co-authors, study design, evidence level (EL), and keywords were evaluated. Publication years were divided into three main periods to compare metrics: 1990-2000, 2001-2010, and 2011-2022. Study designs were categorized into the following five groups: review (narrative and systematic), *in vitro* (part of dental tissue, tooth section, and cell culture), *ex vivo* (complete teeth and animal study), clinical observational studies (case reports), and clinical experimental studies (clinical trial and randomized clinical trial, RCT).

The VOSviewer (version 1.6.18; Leiden University Center for Science and Technology Studies, Leiden, Netherlands, available at https://www.vosviewer.com) was accessed to process the bibliometric data. This software provides a science map for summarizing and visualizing the network between keywords. Used keywords less frequently than two were excluded to improve the map's clarity.

Statistical analysis

All statistical analyses were done using IBM SPSS (SPSS Inc., Chicago, IL, USA) version 26. The level of agreement between two independent researchers was measured with Cronbach's alpha coefficient. The Shapiro-Wilk test was used to determine the normality of the citation number and citation density. The Kruskal-Wallis test was performed to compare these metrics among time periods. The Mann-Whitney U test was performed for pair comparisons. The correlation between citation, citation density and age of publication was evaluated using the square of the Spearman linear coefficient. The significance level was set at $p<0.05$.

Results

Number of citations, citation density, and publication year
A high level of internal consistency was determined by a Cronbach's alpha of 0.975. The top 50 most-cited studies ranked by their citation counts are shown in Table 1, including their citation density ranks. These 50 most-cited articles received 756 citations, with a mean citation per article of 15.12. The citation range was 3 to 62. The total citation density was 67.11, with a mean citation density per article of 1.34. A significant positive association was observed between the number of citations and the age of publication (correlation coefficient = 0.446, $p<0.05$). In addition, there was a significant negative association between citation density and age of publication (correlation coefficient=-0.360, $p<0.05$). Associations are shown in Figure 1.
Between the three periods, the total number of citations had the highest values in 2001-2010 compared to the other periods. There was a significant difference between 1990-2000 and 2011-2022 and 2001-2010 and 2011-2022 ($p<0.05$). The citation density values only differed between 1990-2000 and 2011-2022 ($p<0.05$). Metrics of the top 50 most-cited articles about endo-perio lesions in time periods are presented in Table 2. The highest number of articles was published in 2015 (n=5), followed by 2002 and 2016 (n=4 for each). In 2004, 2009, 2014, and 2017, 3 articles were published.

Journal, country, institution, and authors
The most-cited 50 articles were represented in 24 different journals in total. Among these journals, the *Journal of Endodontics* had the largest number of publications (n=11), followed by the *International Endodontic Journal* (n=5), *Periodontology 2000* (n=4), *Journal of Clinical and Diagnostic Research* (n=3) and *Case Reports in Dentistry* (n=3), *The Journal of the American Dental Association* (n=2), *Journal of Periodontology* (n=2), *International Journal of Dentistry* (n=2), *Journal of Clinical Periodontology* (n=2), and *Photodiagnosis and Photodynamic Therapy* (n=2). Ten of the total journals had only 1 article, as presented in Table 3.
According to the affiliation of the first author, 21 countries were achieved. The United States (US) was leading the most-cited list (n=15), followed by India (n=8). Out of the 42 determined institutions, the University of Southern California was the most productive institution (n=3). All countries and institutions that have contributed with at least two publications are shown in Figure 2.
One hundred and sixty authors contributed to the top 50 most-cited articles. Abbas Bahador, Chi-Chou Huang, Chuen-Chyi Tseng, Ilan Rotstein, James H S Simon, Juan Blanco-Carrión, Maryam Pourhajibagher, Pablo Castelo-Baz, Sanjay Tewari, Se-Lim Oh, and Yea-Huey Melody Chen were the most productive authors with two publications for each. However, Ilan Rotstein, Se-Lim Oh, and Maryam Pourhajibagher were the most frequent first authors.

Figure 1
Association between the number of citations and age of publication **(A)**; association between the citation density and age of publication **(B)**.

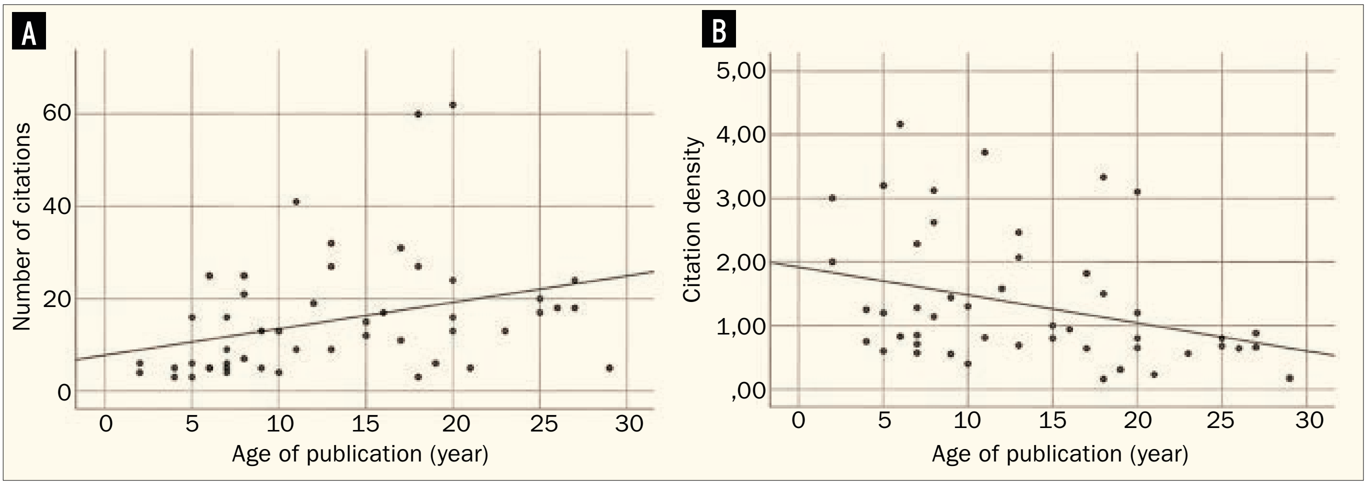

Table 1
The top 50 most-cited articles about endo-perio lesions with the number of citations and citation density from 1990 to 2022.

Citation Rank	Reference	Number of Citation	Citation Density (Rank)
1	Dahlén G. Microbiology and treatment of dental abscesses and periodontal-endodontic lesions. Periodontol 2000. 2002;28:206-239.	62	3.10 (6)
2	Rotstein I, Simon JH. Diagnosis, prognosis and decision-making in the treatment of combined periodontal-endodontic lesions. Periodontol 2000. 2004;34:165-203.	60	3.33 (3)
3	Goyal B, Tewari S, Duhan J, Sehgal PK. Comparative evaluation of platelet-rich plasma and guided tissue regeneration membrane in the healing of apicomarginal defects: a clinical study. J Endod. 2011;37:773-780.	41	3.72 (2)
4	Oh SL, Fouad AF, Park SH. Treatment strategy for guided tissue regeneration in combined endodontic-periodontal lesions: case report and review. J Endod. 2009;35:1331-1336.	32	2.46 (9)
5	Britain SK, Arx T, Schenk RK, Buser D, Nummikoski P, Cochran DL. The use of guided tissue regeneration principles in endodontic surgery for induced chronic periodontic-endodontic lesions: a clinical, radiographic, and histologic evaluation. J Periodontol. 2005;76:450-460.	31	1.82 (13)
6	Abbott PV, Salgado JC. Strategies for the endodontic management of concurrent endodontic and periodontal diseases. Aust Dent J. 2009;54 Suppl 1:S70-85.	27	2.07 (11)
7	Carrotte P. Endodontics: Part 9. Calcium hydroxide, root resorption, endo-perio lesions. Br Dent J. 2004;197:735-743.	27	1.50 (15)
8	Pourhajibagher M, Chiniforush N, Raoofian R, Ghorbanzadeh R, Shahabi S, Bahador A. Effects of sub-lethal doses of photo-activated disinfection against Porphyromonas gingivalis for pharmaceutical treatment of periodontal-endodontic lesions. Photodiagnosis Photodyn Ther. 2016;16:50-53.	25	4.16 (1)
9	Al-Fouzan KS. A new classification of endodontic-periodontal lesions. Int J Dent. 2014;2014:919173.	25	3.12 (5)
10	Harrington GW, Steiner DR, Ammons WF. The periodontal-endodontic controversy. Periodontol 2000. 2002;30:123-130.	24	1.20 (20)
11	Solomon C, Chalfin H, Kellert M, Weseley P. The endodontic-periodontal lesion: a rational approach to treatment. J Am Dent Assoc. 1995;126:473-479.	24	0.88 (25)
12	Schmidt JC, Walter C, Amato M, Weiger R. Treatment of periodontal-endodontic lesions--a systematic review. J Clin Periodontol. 2014;41:779-790.	21	2.62 (8)
13	Chen SY, Wang HL, Glickman GN. The influence of endodontic treatment upon periodontal wound healing. J Clin Periodontol. 1997;24:449-456.	20	0.80 (31)
14	Attam K, Tiwary R, Talwar S, Lamba AK. Palatogingival groove: endodontic-periodontal management–case report. J Endod. 2010;36:1717-1720.	19	1.58 (14)
15	Tseng CC, Chen YH, Huang CC, Bowers GM. Correction of a large periradicular lesion and mucosal defect using combined endodontic and periodontal therapy: a case report. Int J Periodontics Restorative Dent. 1995;15:377-383.	18	0.66 (38)
16	Tseng CC, Harn WM, Chen YH, Huang CC, Yuan K, Huang PH. A new approach to the treatment of true-combined endodontic-periodontic lesions by the guided tissue regeneration technique. J Endod. 1996;22:693-696.	18	0.64 (40)
17	Schwartz SA, Koch MA, Deas DE, Powell CA. Combined endodontic-periodontic treatment of a palatal groove: a case report. J Endod. 2006;32:573-578.	17	0.94 (24)
18	Paul BF, Hutter JW. The endodontic-periodontal continuum revisited: new insights into etiology, diagnosis and treatment. J Am Dent Assoc. 1997;128:1541-1548.	17	0.68 (37)
19	Rotstein I. Interaction between endodontics and periodontics. Periodontol 2000. 2017;74:11-39.	16	3.20 (4)

Table 1
The top 50 most-cited articles about endo-perio lesions with the number of citations and citation density from 1990 to 2022.

Citation Rank	Reference	Number of Citation	Citation Density (Rank)
20	Castelo-Baz P, Ramos-Barbosa I, Martín-Biedma B, Dablanca-Blanco AB, Varela-Patiño P, Blanco-Carrión J. Combined Endodontic-Periodontal Treatment of a Palatogingival Groove. J Endod. 2015;41:1918-1922.	16	2.28 (10)
21	Aryanpour S, Bercy P, Van Nieuwenhuysen JP. Endodontic and periodontal treatments of a geminated mandibular first premolar. Int Endod J. 2002;35:209-214.	16	0.80 (32)
22	Gonzales JR, Rodekirchen H. Endodontic and periodontal treatment of an external cervical resorption. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2007;104:e70-77.	15	1 (23)
23	Simon JH, Glick DH, Frank AL. The relationship of endodontic-periodontic lesions. J Endod. 2013;39:e41-46.	13	1.44 (16)
24	Ahmed HMA. Different perspectives in understanding the pulp and periodontal intercommunications with a new proposed classification for endo-perio lesions. Endod Pract. 2012;6:87-104.	13	1.30 (17)
25	Haueisen H, Heidemann D. Hemisection for treatment of an advanced endodontic-periodontal lesion: a case report. Int Endod J. 2002;35:557-572.	13	0.65 (39)
26	Wei PC, Geivelis M, Chan CP, Ju YR. Successful treatment of pulpal-periodontal combined lesion in a birooted maxillary lateral incisor with concomitant palato-radicular groove. A case report. J Periodontol. 1999;70:1540-1546.	13	0.56 (44)
27	Ballal NV, Jothi V, Bhat KS, Bhat KM. Salvaging a tooth with a deep palatogingival groove: an endo-perio treatment–a case report. Int Endod J. 2007;40:808-817.	12	0.80 (33)
28	Vakalis SV, Whitworth JM, Ellwood RP, Preshaw PM. A pilot study of treatment of periodontal-endodontic lesions. Int Dent J. 2005;55:313-318.	11	0.64 (41)
29	Varughese V, Mahendra J, Thomas AR, Ambalavanan N. Resection and Regeneration - A Novel Approach in Treating a Perio-endo Lesion. J Clin Diagn Res. 2015;9:Zd08-10.	9	1.28 (18)
30	Gandhi A, Kathuria A, Gandhi T. Endodontic-periodontal management of two rooted maxillary lateral incisor associated with complex radicular lingual groove by using spiral computed tomography as a diagnostic aid: a case report. Int Endod J. 2011;44:574-582.	9	0.81 (30)
31	Karabucak B, Setzer FC. Conventional and surgical retreatment of complex periradicular lesions with periodontal involvement. J Endod. 2009;35:1310-1315.	9	0.69 (36)
32	Kambale S, Aspalli N, Munavalli A, Ajgaonkar N, Babannavar R. A sequential approach in treatment of endo-perio lesion a case report. J Clin Diagn Res. 2014;8:Zd22-24.	7	1.14 (22)
33	Ustaoğlu G, Uğur Aydin Z, Özelçi F. Comparison of GTR, T-PRF and open-flap debridement in the treatment of intrabony defects with endo-perio lesions: a randomized controlled trial. Med Oral Patol Oral Cir Bucal. 2020;25:e117-e123.	6	3 (7)
34	Pourhajibagher M, Bahador A. Evaluation of the crystal structure of a fimbrillin (FimA) from Porphyromonas gingivalis as a therapeutic target for photo-activated disinfection with toluidine blue O. Photodiagnosis Photodyn Ther. 2017;17:98-102.	6	1.20 (21)
35	Gupta S, Tewari S, Tewari S, Mittal S. Effect of Time Lapse between Endodontic and Periodontal Therapies on the Healing of Concurrent Endodontic-Periodontal Lesions without Communication: A Prospective Randomized Clinical Trial. J Endod. 2015;41:785-790.	6	0.85 (26)
36	Yu L, Xu B, Wu B. Treatment of combined endodontic-periodontic lesions by intentional replantation and application of hydroxyapatites. Dent Traumatol. 2003;19:60-63.	6	0.31 (47)
37	Alquthami H, Almalik AM, Alzahrani FF, Badawi L. Successful Management of Teeth with Different Types of Endodontic-Periodontal Lesions. Case Rep Dent. 2018;2018:7084245.	5	1.25 (19)

Table 1
The top 50 most-cited articles about endo-perio lesions with the number of citations and citation density from 1990 to 2022.

Citation Rank	Reference	Number of Citation	Citation Density (Rank)
38	Pico-Blanco A, Castelo-Baz P, Caneiro-Queija L, Liñares-González A, Martin-Lancharro P, Blanco-Carrión J. Saving Single-rooted Teeth with Combined Endodontic-periodontal Lesions. J Endod. 2016;42:1859-1864.	5	0.83 (27)
39	Nadig PP, Agrawal IS, Agrawal VS, Srinivasan SC. Palato-Radicular Groove: A Rare Entity in Maxillary Central Incisor Leading To Endo-Perio Lesion. J Clin Diagn Res. 2016;10:Zj14-15.	5	0.83 (28)
40	Fahmy MD, Luepke PG, Ibrahim MS, Guentsch A. Treatment of a Periodontic-Endodontic Lesion in a Patient with Aggressive Periodontitis. Case Rep Dent. 2016;2016:7080781.	5	0.83 (29)
41	Miao H, Chen M, Otgonbayar T, Zhang SS, Hou MH, Wu Z, et al. Papillary reconstruction and guided tissue regeneration for combined periodontal-endodontic lesions caused by palatogingival groove and additional root: a case report. Clin Case Rep. 2015;3:1042-1049.	5	0.71 (35)
42	Coraini C, Mascarello T, de Palma CM, Gobbato EA, Costa R, de Micheli L, et al. Endodontic and periodontal treatment of dens invaginatus: Report of 2 clinical cases. G Ital Endod. 2013;27:86-94.	5	0.55 (45)
43	Niemiec BA. Treatment of mandibular first molar teeth with endodontic-periodontal lesions in a dog. J Vet Dent. 2001;18:21-25.	5	0.23 (48)
44	Zubery Y, Kozlovsky A. Two approaches to the treatment of true combined periodontal-endodontal lesions. J Endod. 1993;19:414-416.	5	0.17 (49)
45	Katwal D, Fiorica JK, Bleuel J, Clark SJ. Successful Multidisciplinary Management of an Endodontic-Periodontal Lesion Associated With a Palato-Radicular Groove: A Case Report. Clin Adv Periodontics. 2020;10:88-93.	4	2 (12)
46	Olczak K, Pawlicka H. Mineral trioxide aggregate in treatment of permanent teeth with open apex and endo-perio lesions. A case report. Eur J Paediatr Dent. 2015;16:287-289.	4	0.57 (43)
47	Oh SL. Mesiobuccal root resection in endodontic-periodontal combined lesions. Int Endod J. 2012;45:660-669.	4	0.40 (46)
48	Dhoum S, Laslami K, Rouggani F, El Ouazzani A, Jabri M. Endo-Perio Lesion and Uncontrolled Diabetes. Case Rep Dent. 2018;2018:7478236.	3	0.75 (34)
49	Betancourt P, Elgueta R, Fuentes R. Treatment of endo-periodontal lesion using leukocyte-platelet-rich fibrin. A case report. Colomb Med (Cali). 2017;48:204-207.	3	0.60 (42)
50	Aqrabawi J, Jarbawi MM. The healing potential of periodontal-endodontic lesions. Int Dent J. 2004;54:166-170.	3	0.16 (50)

Study design, evidence level, and keywords
Clinical observational studies (case reports=29) were found to be the most frequent study design, followed by review (narrative review=12 and systematic review=1), *in vitro* (n=2), *ex vivo* (n=2), and clinical experimental studies (clinical trial=2 and RCT=2).
ELs were categorized into five groups (27): EL I: systematic reviews and meta-analysis, EL II: RCTs, EL III: cohort studies and clinical trials, EL IV: case-control series, EL V: case series and case reports. Since reviews (except systematic review of RCTs), *in vitro*, and *ex vivo* studies belong to the bottom of the EL pyramid, the frequency of each level was as follows: EL I (n=1), II (n=2), III (n=2), and V (n= 45).
Among the top 50 most-cited articles, the VOSviewer software recovered 109 keywords. After reducing the number of co-occurrences to two, 16 keywords (nodes)

Table 2
The number of citations and citation density values of the top 50 most-cited articles about endo-perio lesions in time periods.

	1990-2000 n=7	2001-2010 n=18	2011-2022 n=25	Comparison *p* value*
Number of citations	16.42[1]	21.61[1]	10.44[2]	<.05
Min-Max	5-24	3-62	3-41	
Total	115	389	261	
Citation density	0.62[x]	1.29[x,y]	1.57[y]	<.05
Min-Max	0.17-0.88	0.16-3.33	0.4-4.16	
Total	4.39	23.28	39.44	

[a]Median. Min-Max: Minimum and Maximum values.
**The Shapiro-Wilk test showed no normality. The Mann-Whitney U test analyzed pair comparisons. Read horizontally; the different superscript numbers and letters indicate a significant difference.*

were grouped into five clusters and a maximum of 1000 lines were loaded. The network of keywords is shown in Figure 3. "Endo-perio lesions" (n=10), followed by "guided tissue regeneration" (n=7), "palatogingival groove" (n=4), and "root canal treatment" (n=4) were found to be the most frequent keywords.

Discussion

Diagnosis and treatment of endo-perio lesions present challenges because of the anatomical and functional similarities (28, 29). Integrating multidisciplinary treatment approaches with newly developed materials and appropriate techniques leads to better outcomes (30, 31). Various well-designed studies have been performed in this scope to provide accurate aspects and treatment options for endo-perio lesions (17, 32, 33). Based on the present knowledge, the goal of this bibliometric study is to exhibit the process of endo-perio lesions through changing developments and trends with the aid of the top 50 most-cited articles.

The year of publication significantly impacts the citation count that an article receives. Since the number of citations is

Figure 2
All contributed countries and institutions with at least 2 publications.

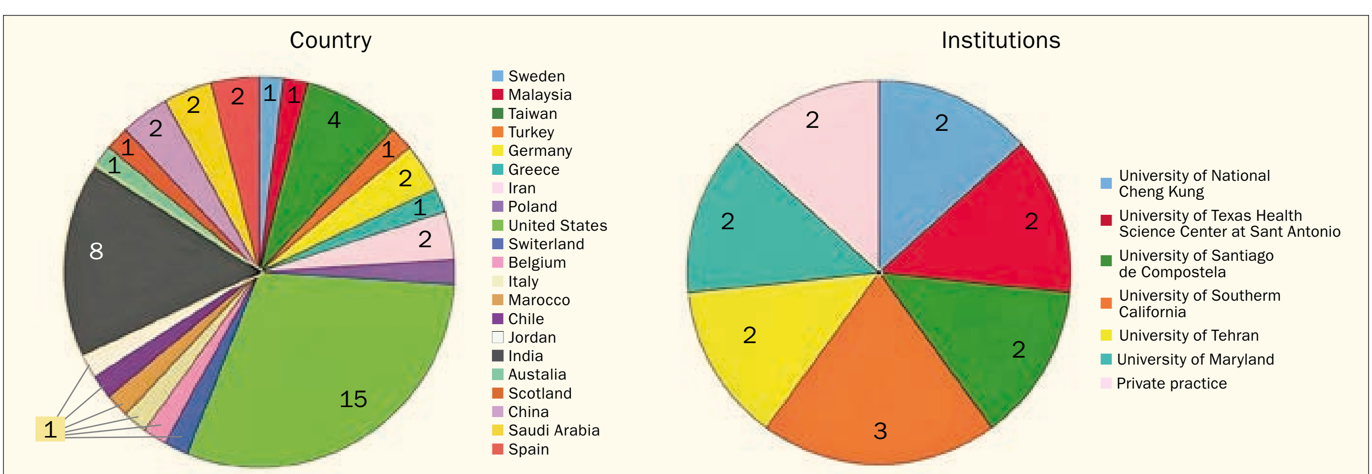

Table 3
Journals with the top 50 most-cited articles

Name of the journal	Number of articles
Journal of Endodontics	11
International Endodontic Journal	5
Periodontology 2000	4
Journal of Clinical and Diagnostic Research	3
Case Reports in Dentistry	3
The Journal of the American Dental Association	2
Journal of Periodontology	2
International Journal of Dentistry	2
Journal of Clinical Periodontology	2
Photodiagnosis and Photodynamic Therapy	2
Australian Dental Journal	1
British Dental Journal	1
Endodontic Practice Today	1
Oral Surgery, Oral Medicine, Oral Pathology, Oral Radiology, and Endodontology	1
Medicina Oral Patologia Oral y Cirugia Bucal	1
Journal of Veterinary Dentistry	1
European Journal of Paediatric Dentistry	1
Dental Traumatology	1
The International Journal of Periodontics & Restorative Dentistry	1
Giornale Italiano di Endodonzia	1
Clinical Case Reports	1
Clinical Advances in Periodontics	1
Colombia Médica	1
International Dental Journal	1

a time-dependent metric (34), older publications are expected to gain more citations than recently published articles (35). There was a significant positive correlation between the number of citations and the age of publication in accordance with the nature of citation analysis. However, interestingly, this metric had the highest counts in the period 2001-2010. It can be explained by the fact that innovations in treatment protocols and materials have led clinicians to follow new trends and publish their knowledge and experiences with high quality and effect, especially in this period (36). However, time is still needed to see if these publications will receive more citations as time goes on. In this aspect, citation density which is the time-normalized metric could be a valid alternative to detect the importance of the new articles to the readership.

In this study, the three most-cited articles aimed to give an aspect about the definition, clinical characterization, treatment of endo-perio lesions, treatment of combined perio-endo lesions, and the evaluation of the efficacy and equivalence of platelet-rich plasma with guided tissue regeneration membrane during the treatment of apicomarginal defects. Among the 50 most-cited articles, it was observed that the developments in techniques and materials were mainly actualized in the field of periodontology. Although novel therapeutic approaches such as photo-activated disinfection (37), using silver nanoparticles (9) and diode lasers (7) were suggested in order to increase the efficiency of endodontic disinfection, there is a lack of information about utilizing these methods for clinical applications. Thus, further studies are needed to determine the impact of different endodontic treatment protocols on the healing process of endo-perio lesions.

The highest number of publications were published mainly in two well-recognized and influential journals in endodontics (38). Prolific journals constitute a significant percentage of all articles in a particular specialty and are then widely cited by subsequent articles (39). However, multidisciplinary journals that publish studies from all fields of dentistry made up the vast majority. The combined nature of endo-perio lesions can explain why this topic cannot be evaluated in a single area. Moreover, the publication of a study related to the subject in the veterinary journal is another striking result. Easier manage-

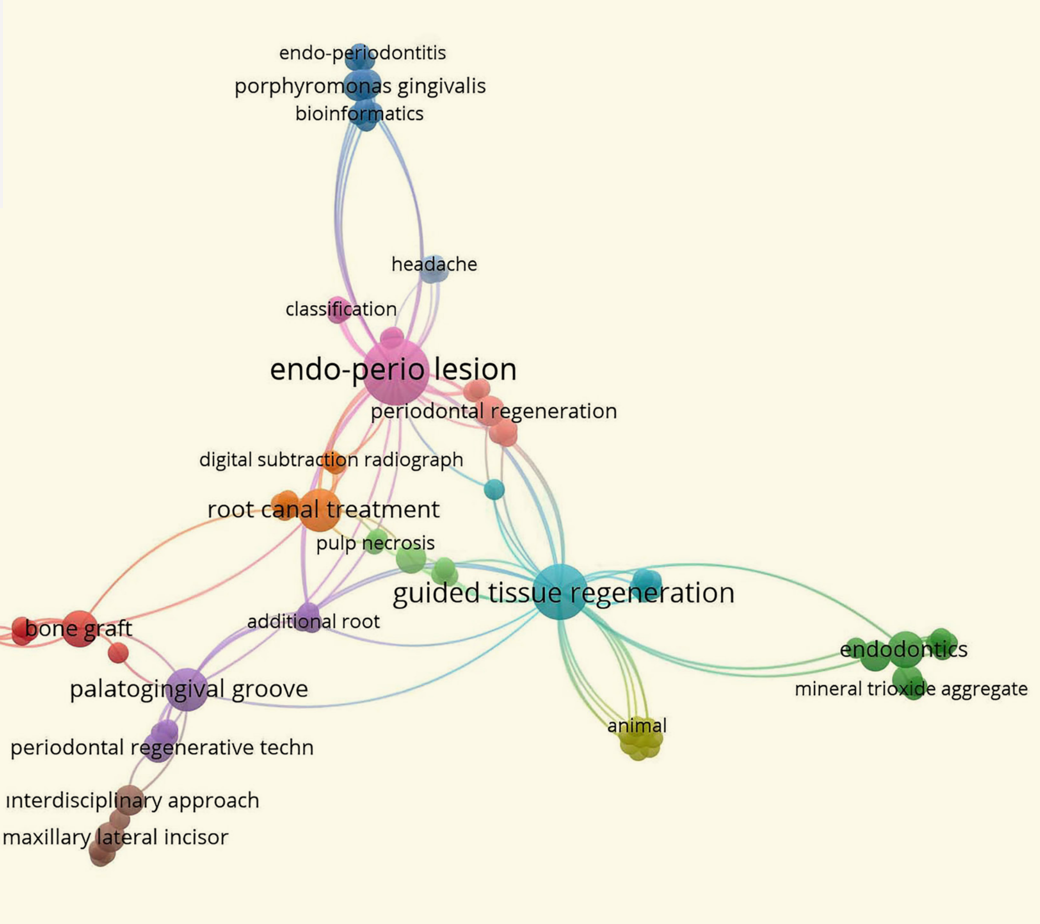

Figure 2
The network of frequently used two or more co-occurring keywords of the top 50 most-cited articles. There are 16 nodes, 5 clusters, and a maximum of 1,000 lines.

ment of treatment methods and follow-up in animals may have led to animal studies being conducted and published in related journals.

In line with many other studies, the US was the most productive country with 15 most-cited articles (26, 36, 39). A significant amount of funding towards research and the large size of the scientific society is making the US a leading country in terms of innovation in science and technology (40). India contributed to this study with the eight most-cited articles. This result is also understandable since National Science Foundation ranked India as the third-biggest knowledge. During the last two decades, India has been growing daily regarding performing scientific work and obtaining research output (41).

Among the institutes from which most of the first authors were affiliated, 11 of them pertained to the US. The University of Southern California was the most prolific institution in total. Publications from the University of Southern California have appraised the interrelationship between endo-perio lesions and provided biological and clinical evidence for diagnosis, prognosis, and treatment of these conditions. Interestingly, the highest number of published articles per author was two. Therefore, among these eleven authors, no one contributed more considerably than the others to this bibliometric study. This result can be interpreted as that only a particular group of authors does not tend to work on the management of endo-perio lesions, and various authors have orientations on variable subjects within this field. More than half of the 50 most-cited studies were case reports, followed by reviews, and this is compatible with lower citation counts in total and for each selected article. Although case reports guide other clinicians by describing treatment approaches in a specific situation, there is a tendency for fewer citations to case reports (42). A possible reason can be that case reports about endo-perio lesions often report rarely-seen complicated cases on a small number of patient groups. However, selected treatment modalities for endo-perio lesions are needed to investigate with RCTs to make a general assessment. Interestingly, there are few clinical trials in the literature about endo-perio lesions (15, 28). It may be considered that the poor coordination between departments and the difficulties in diagnosing and classifying patients within the scope of endo-perio lesions cause an insufficient number of RCTs. On the other hand, reviews tend to be cited more often since these publications give comprehensive information about relevant fields (43). This study, as the first and second most-cited articles are narrative reviews, is consistent with the above-mentioned information.

This bibliometric study has some limitations that should be addressed. Firstly, citation analysis was used in this bibliometric study, and this metric is time-dependent. Therefore, fairly recent articles with good content and quality might have been missed. In addition, the citation count does not distinguish between positive and negative citations. Therefore, an article published on a critical trend may lead to being received more citations (42). Secondly, although the WoS is considered the most beneficial database to find and analyze high-quality publications, particularly in health sciences, it is difficult to be sure whether this database conclusively records all articles published in all journals compared to, i.e., Scopus. Finally, the institutional address of the first authors was selected to list as the primary contributing institution; consequently, only those institutions and countries could be established.

Conclusion

It can be concluded that successfully treating endo-perio lesions depends on accurate diagnosis and proper treatment strategy involving both endodontics and periodontics. Developments in materials and techniques could improve the outcomes. Future RCTs are needed to observe these methodologies' actual impact on the clinic definitively.

Clinical Relevance

The improved materials and techniques in the management of endo-perio lesions have led to better treatment outcomes. Identifying the contemporary research areas could be beneficial to address new investigations in the near future.

Conflict of Interest

None.

Acknowlegments

None.

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ORIGINAL ARTICLE

The outcome of root canal treatment with a calcium silicate-based sealer of necrotic teeth: a retrospective assessment

ABSTRACT

Aim: *This retrospective clinical assessment aimed to evaluate the healing effect of calcium silicate-based root canal sealers on necrotic teeth with periapical lesions.*
Methodology: *An assessment of the outcome was carried out based on the patient's clinical records and radiographic data. The study involved 20 teeth in total: 9 of which were posterior and 11 anterior. Obturation was performing using either a single cone or a lateral compaction technique. The differences in sizes of lesions were characterized as large, medium, and small lesion sizes. Initial, final, and follow up periapical radiographs were taken and scored with the aid of periapical index scoring system.*
Results: *The mean follow-up period was 15.8 months. Interobserver agreement was evaluated by Kappa test and categorical variables were evaluated by Fisher's Exact test. The overall success rate was 100%, with 70% of patients being fully healed and 30% assessed as healing. Variables did not differ statistically significant.*
Conclusion: *Calcium silicate-based sealers have good healing capacity even in the presence of significant periapical lesions.*

Ayşenur Kamacı Esen[1*]

Fahrettin Kalabalık[2]

[1]Sakarya University, Faculty of Dentistry Department of Endodontics, Turkey.
[2]Sakarya University Faculty of Dentistry Department of Oral Diagnosis and Radiology, Turkey.

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Corresponding Author
Ayşenur Kamacı Esen, Sakarya University Faculty of Dentistry Department of Endodontics, Sakarya, Türkey.
E-mail: a.kamaci@windowslive.com | Tel. 00905346137213

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Introduction

In cases of apical periodontitis, root canal therapy aims to minimize the amount of bacteria in the root canal space and promote periapical healing (1). Hermetic root canal obturation is an essential step when attempting to initiate periapical healing. Historically, gutta-percha has been the most commonly used obturation material (2). However, it does not adhere to dentin walls and cannot fill root canal defects if thermoplastic gutta-percha techniques are not applied (3, 4). Gutta-percha is typically used with root canal sealers due to the unfavorable effects of the substance. Root canal sealers are a crucial component in hermetic root canal obturation as they adhere to root canal walls and gutta-percha, aid in tridimensional root canal obturation by filling in irregularities in the canal, eradicate germs, and stop bacteria from receiving nourishment (5). Resin-based root canal sealers have been the gold standard for many years due to their low solubility, adequate dimensional stability and strong bonding strength (6). However, due to their lack of bioactive characteristics, resin-based root canal sealers do not promote bone formation (6).

Calcium silicate-based root canal sealers have been introduced to the market with the ideal properties including; antimicrobial effect, hydrophilicity, biocompability, biomineralization, hydroxyapatite formation, adhesion, and bioactivity (7, 8). Calcium silicate-based sealers require dentinal tubule moisture for setting (9, 10). Due to the sealer's mechanism of setting, any residual moisture has no negative effects. Calcium silicate-based sealers that are extruded from the apex are also considered to be biocompatible (11). Due to their larger film thickness compared to resin-based root canal sealers (12), calcium silicate-based sealers have a lesser dentinal tubule penetration (13). Despite this drawback when compared to resin-based root canal sealers, they have been associated with an increase in root canal treatment success rates (14, 15) thanks to the bioactive features of the previously mentioned calcium silicate-based sealers. When calcium silicate-based sealers were first introduced to the market, their use in combination with thermoplastic gutta-percha systems was not recommended due to worries that high temperatures could have a negative influence on the sealer's characteristics (11). Nevertheless, the use of calcium silicate-based sealers in conjunction with cold gutta-percha in techniques like single cone and lateral compaction obturation appears to be favorable in terms of being simple to use, requiring no additional material or time, and being non-irritating when in contact with periapical tissue (16, 17).

The aim of the present study is to assess the success rate of calcium silicate-based root canal sealer in necrotic teeth with periapical bone destruction.

Materials and Methods

Case selection and treatment procedure

The Non-Invasive Research Ethics Committee at Sakarya University granted approval (E-71522473-050.01.04-202820-353) for the study. The information was gathered from the records of the patients that were treated between September 2020 and February 2022 at the Sakarya University, School of Dentistry, Department of Endodontics. The following criteria were used for inclusion and exclusion:

Inclusion criteria

- Teeth with X-rays adequate quality for preoperative and postoperative evaluation,
- Teeth with fully developed root canals,
- Root canal therapy of radiologically acceptable quality (all canals adequately sealed within 2 mm of the radiological apex, no broken files, etc.),
- Satisfactory coronal restoration
- Patients who attended follow-up appointments.

Exclusion criteria

- MTA or resin-based root canal sealers that were used to complete the root canal filling.
- Teeth with open apices,
- Severe periodontal loss,

- Treatments which were carried out in a single session,
- Vital pulp root canal treatment,
- Patients that did not show up for their follow-up appointments,
- Teeth that were underwent periapical surgery following root canal therapy (Figure 1).

Treatment protocol

All root canal procedures and follow-ups were carried out by a single endodontic specialist with more than five years of experience. A standardized treatment protocol was utilized and performed in two sessions. A rubber dam was placed, and the access cavity was opened following the injection of local anesthetic (1,8 ml lidocaine with 1:100,000 epinephrine). Any coronary restorations and caries were removed. Working length was determined with an apex locator (Woodpex III, Woodpecker, Guilin, China) and a size 10 K file (Micro Mega, Besancon, France). Depending on the operator's instrumentation preference, either the crown-down approach or the step-back technique was used for root canal enlargement. ProTaper next (Dentsply Maillefer, Ballaigues, Switzerland) rotary files were used when crown down instrumentation was performed. The canals were irrigated with 3% NaOCl (Coltene/Whaledent, Switzerland) between each instrument using 30 G side-vented irrigation tips (Endo Eze Tip, Ultradent Products). During the first visit, root canal shaping and debriment was completed using either step-back or crown-down technique according to root canal anatomy, followed by temporization via calcium hydroxide paste (Cerkamed, Stalowa Wola, Poland). After application of calcium hydroxide, a teflon tape was used to cover root canal orifices and glass ionomer cement (Ionofil, VOCO, Cuxhaven, Germany) was used as a temporary restoration.

In the second session, the temporary restoration was removed while using a rubber dam to isolate the teeth under local anesthetic. The calcium hydroxide in the canals was then removed using irrigation and sonic activation (EDDY; VDW, Munich, Germany). Each root canal was irrigated with 2.5 mL of 5% EDTA, 5 mL of 3% NaOCl, 2.5 mL of distilled water, and 2.5 mL of 2% chlorhexidine during final irrigation. NaOCl was activated for 20 seconds with the EDDY sonic activation system during the final stage of irrigation. After drying with paper points, the root canals were filled with gutta-percha and calcium silicate-based sealer (Ceraseal, Meta Biomed Co., Cheongju, Korea) using either lateral compaction or single cone technique, depending on the technique used for root canal enlargement. Patients were advised to attend their follow-up appointments every six months. Bulk-fill resin SDR (Dentsply Sirona, Charlotte, NC, USA) and composite resin (Tokuyama Estelite Posterior, Tokyo, Japan), were used to fill the access cavity in cases where a permanent restoration was placed. If a prosthetic restoration was indicated, the access cavity was temporarily sealed with glass ionomer cement, and the patients referred to the Department of Prosthodontics as soon as possible. All procedures were performed under an operating microscope (Zumax OMS2350, Zumax Medical Co. Ltd, Jiangsu, China).

Recall appointments included clinical and radiographic examinations of the treated tooth, and the results were recorded and filled. The patient admissions system was used to retrieve retrospective radiographic data.

Radiographs were evaluated by two calibrated examiners. Teeth were all scored according to their healing process and periapical index (PAI) scoring system (18).

1. Healed: functional, asymptomatic teeth with no or minimal radiographic periradicular (apical) pathosis (radiolucency)
2. Unhealed: nonfunctional, symptomatic teeth with or without radiographic periradicular (apical) pathosis (radiolucency) or asymptomatic teeth with unchanged, new, or enlarged radiographic periradicular (apical) pathosis (radiolucency).
3. Healing: teeth that are asymptomatic and functional with a decreased size of radiographic periradicular (apical) pathosis (radiolucency).

Table 1
Relationship between sociodemographic characteristics of patients and healing status

	Status		p
	Healed	Healing	
Age			
18-45	10 (76,9)	3 (23,1)	1,000
46-76	4 (66,7)	2 (33,3)	
Teeth			
Anterior	9 (81,8)	2 (18,2)	0,336
Posterior	5 (55,6)	4 (44,4)	
Lesion size			
Large	10 (71,4)	4 (28,6)	0,587
Small	2 (100)	0 (0)	
Medium	2 (50)	2 (50)	
Gender			
Male	8 (66,7)	4 (33,3)	1,000
Female	6 (75)	2 (25)	
Follow-up period			
18 months	8 (66,7)	4 (33,3)	1,000
>18 months	6 (75)	2 (25)	
Restoration			
Bridge	3 (75)	1 (25)	0,380
Crown	1 (50)	1 (50)	
Post+crown	0 (0)	1 (100)	
Sdr+composite	10 (76,9)	3 (23,1)	
Apical sealer extrusion			
Yes	5 (62,5)	3 (37,5)	0,642
No	9 (75)	3 (25)	
Obturation Technique			
Lateral compaction	6 (85,7)	1 (14,3)	0,354
Single cone	8 (61,5)	5 (38,5)	

Fisher's Exact Testi

PAI 1: Normal periapical bone structure.
PAI 2: Small changes in bone structure, no demineralization.
PAI 3: Changes in bone structure with some diffuse mineral loss.
PAI 4: Apical periodontitis with well-defined radiolucent area.
PAI 5: Severe apical periodontitis, exacerbating features.
Both healed and healing cases were considered as successful and unhealed cases were considered as failure. Age, periapical lesion size, coronary restoration type, sealer extrusion, and follow-up time were among the patient- and tooth-related characteristics that were assessed. The age of the patients was divided into two categories; those under 45 and those older than 45. Small lesions (0-2 mm), medium lesions (2-5 mm), and large lesions (greater than 5 mm) were classified according to the size of the periapical lesion.

Statistical Analysis
The data was analyzed with SPSS (version 23; IBM Corp, Armonk, NY). Pearson Chi-square test and Fisher's Exact test were used to compare categorical variables according to healing status. Kappa test was used to evaluate the interobserver agreement.

Results

A significantly high level of interobserver agreement was found between observer 1 and observer 2 in terms of healing evaluation (ℜ=0,875; p<0,001). Nine posterior teeth and eleven anterior teeth out of the 20 total teeth were included in the study. The categorical variables are shown in Table 1.

Clinical and radiographic evaluation
Fourteen teeth with large lesions and 4 teeth with medium lesions were categorized as healed and healing while 2 teeth with small lesions were categorized as healed. There were no teeth identified as unhealed; all of the evaluated teeth were either healed or healing (Table 1, Figure 2, 4). No significant difference was found between any of the variables and the healing status evaluated in the study (p>0.05).

Outcome assessment
The majority of lesions were categorized as large lesions (Table 1). The mean follow-up period is 15.8 months, with the shortest follow-up period being 11 months and the longest being 24 months. To determine the influence of patient-related factors on healing status, patient ages were

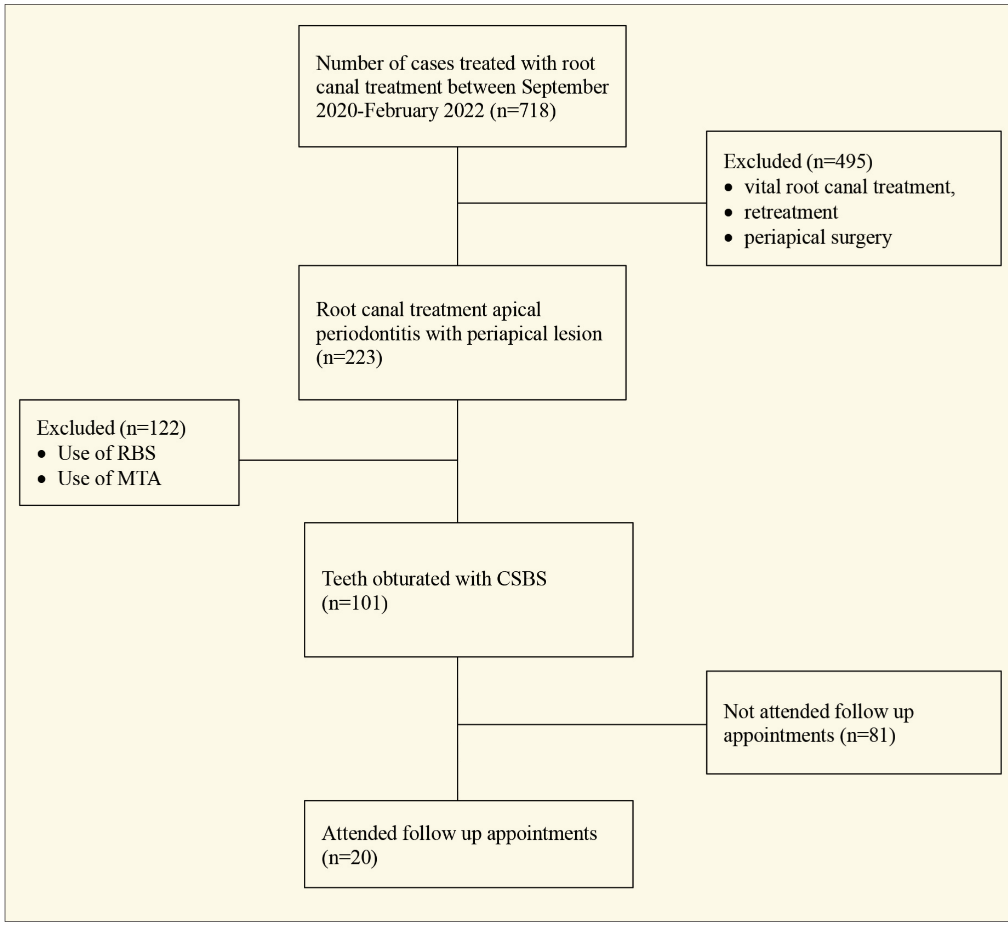

Figure 1
Flowchart allocation of patient inclusion to the study.

n=Number of cases, RBS=Resin-based root canal sealers, MTA=Mineral trioxide aggregate, CSBS=Calcium silicate-based sealers.

divided into groups of 18 to 45 and 46 to 76, lesion sizes into large, medium, and small, and follow-up times into longer than 18 months and less than 18 months. Patients' age, gender, restoration type, compaction technique, and presence of extruded sealer (Figure 3) were also evaluated. None of the variables showed statistical significance (p>0.05).

Discussion

To enhance the effectiveness of root canal therapy, calcium silicate-based root canal sealers have been introduced into endodontic practice (19). Due to microbial involvement, the success rate of root canal therapy in necrotic teeth is lower than in vital teeth (20). There has been recent research have focused on different aspects of the effects of calcium silicate-based root canal sealers. There are some studies showing the effect of resin-based root canal sealers and calcium silicate-based sealers on postoperative pain (21, 22). Other studies have been published with a focus on the outcome of calcium silicate-based sealers. However, none of the previous studies were focused solely on the effects of calcium silicate-based root canal sealers on necrotic teeth with periapical lesion (8, 23-25). This study appears to be the first in that sense.

Endodontic treatments are performed as single or multiple sessions depending on the condition of the teeth requiring root canal treatment. Despite the fact that there are no conclusive studies demonstrating that single-session endodontic treatment is superior to multi-session therapy (26, 27), single-visit endodontic treatment is commonly preferred since it keeps the patient motivated and reduces the risk of bacterial leakage and the associated flare-ups (26, 28, 29). However, in the presence of infected root canal system with periapi-

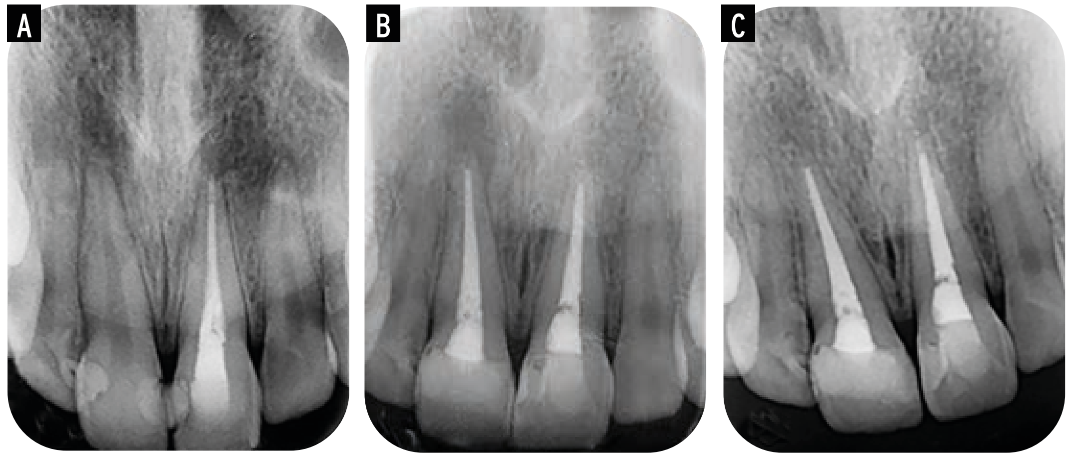

Figure 2
A clinical case of a healed lesion: **A)** preoperative radiograph of right central incisor **B)** postoperative radiograph **C)** 24 months follow up radiograph showing healing with no clinical signs and symptoms.

cal lesions intracanal medicament placement is advised in order to properly disinfect the root canal system (30). In the current study, multiple visit endodontic treatment was preferred due to the presence of periapical lesions in necrotic teeth. Unlike other studies (23-25), all cases were treated by the same endodontist. This is one of the advantages that sets our study apart from previous studies in terms of standardization. Different irrigation protocols were performed in previous studies, Salah et al. (8) used only 17% EDTA for final irrigation, Chybowski et al. (24) used the same concentration of EDTA along with passive ultrasonic irrigation, Coşar et al. (23) used 17% EDTA and 2.5% NaOCl for final irrigation. In the present study 5% EDTA, 3% NaOCl, distilled water, and 2% chlorhexidine was used as irrigation solution. Furthermore, NaOCl was activated with a sonic activation system.

Due to its adequate ability to remove the smear layer and reduced the risk of dentinal erosion, 5% EDTA was selected over 17% EDTA (31). Chlorhexidine was utilized as a final irrigation solution, because of its impact on biofilm and endotoxins, as well as its beneficial effects on the durability of coronal restorations and the endodontic therapy (32).

Recent advancements in calcium silicate-based root canal sealers have rendered these sealers useable with warm obturation procedures (33). Nevertheless, cold obturation techniques are still frequently preferred due to their convenience of use. Vasconcelos et al. (34) reported that 41.3% of the endodontists and 95.7% of the academicians preferred to use cold obturation techniques for root canal obturation. In the present study, cold obturation techniques were used due to its ease of use and not requiring extra materials or time (16,

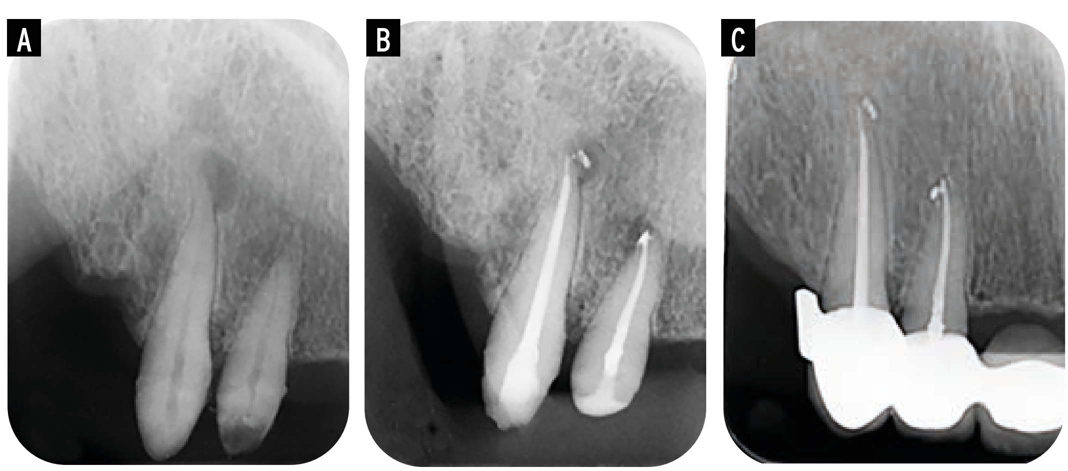

Figure 3
A clinical case of apically extruded sealer: **A)** preoperative radiograph of upper right lateral and canine teeth **B)** postoperative radiograph **C)** 13 months follow up radiograph showing significant level of healing with no clinical signs and symptoms.

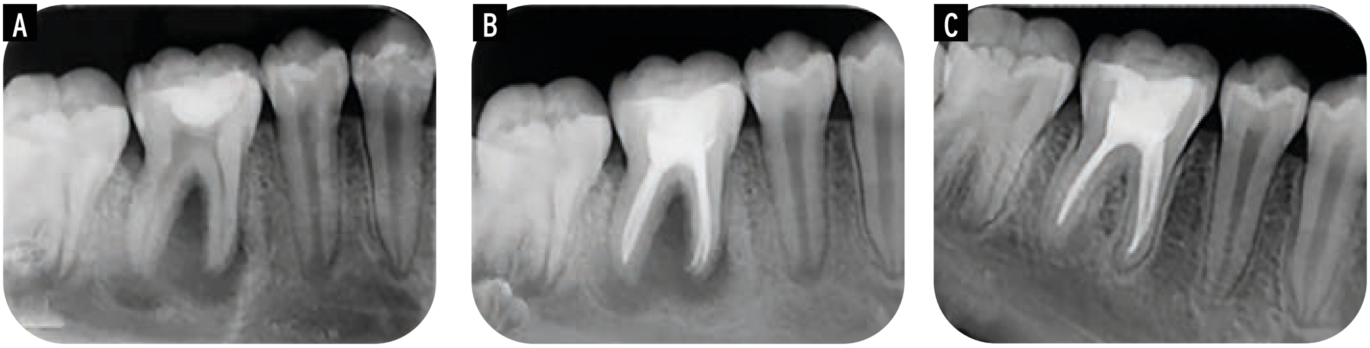

Figure 4
A clinical case of a healing lesion: **A)** preoperative radiograph of right mandibular molar teeth; **B)** postoperative radiograph; **C)** 21 months follow up radiograph showing healing is still in process with no clinical signs and symptoms.

17). Root canal preparation technique was determined according to root canal anatomy; while stepback techinique was preferred for oval shaped and wide canals, crown down tecnique was pereferred for round shaped canals. The obturation choice was made according to root canal preparation technique. Same techniques were used in the majority of outcome studies involving the use of calcium silicate-based root canal sealers (24, 25, 35).
To the best of our knowledge, there currently are no studies which have investigated the effect of calcium silicate-based root canal sealers solely on necrotic teeth with periapical lesions. However, various results were achieved with different endodontic diagnoses in the outcome studies. Chybowski et al. (24) reported a success rate of 90.6% for initial treatment, 91.7% for retreatment with mean 18.6 months follow up while Coşar et. al (23) reported slightly a lesser success rate of 88.6% for initial treatment with the 24 months follow up. Zavattini et al. (14) reported 84% for necrotic and vital teeth for 12 months follow up but where they differed from current study they used cone beam computed tomography (CBCT) images to evaluate healing. Pontoriero et al. (36) reported a 99% success rate for the initial and retreatment groups but they used different brands of calcium silicate-based sealers with warm vertical compaction technique with mean a 18 months follow up period. In the current study, a mean follow-up period of 15.6 months showed a 100% success rate. Of all the cases, 75% had fully recovered. This finding seems compatible with the study of Pontoriero et. al. (36) but slightly higher than the rest of the previous studies (14, 23, 24). This increased success rate may be attributed to the use of calcium hydroxide as intracanal medicament, additional antimicrobial effect gained by chlorhexidine, or treatment of all cases by the same experienced endodontist. However, evaluation of cases was performed only according to periapical X-rays in the present study. Compared to periapical X-rays, the accuracy of lesion follow-up with CBCT images is higher. On the other hand, a CBCT examination performed for the follow-up of endodontic treatments results in a higher radiation dose compared to periapical radiographs (37). Therefore, due to the increased radiation dose associated with CBCT exams, periapical radiography is the most often utilized approach for the follow up of endodontic treatments (38).
In a previous study reported by AlBakhakh et al. (35), periapical lesions were divided into three subgroups; as small, medium, and large similar to the present study. They showed that small and medium lesions had a significantly higher success rate compared to large lesions. Another study performed by Pontoriero et. al. (36) divided periapical lesions as larger than 5 mm and smaller than 5 mm and they found that small lesions have faster healing capacity. Contrary to these studies, no significant difference was observed between lesions sizes in terms of healing capacity in the present study. However, it should be emphasized that the sample sizes of large, medium and small lesions are not equal. Since most of the lesions found in the study are categorized as large lesions, it will not be very accurate to compare them with other groups.

According to the results of the present study, as highlighted in a previous study (36), it was thought that operator knowledge and experience had a significant impact on the prognosis of endodontic treatment. However, it is also obvious that calcium silicate-based sealers have undeniable healing potential.

There are also some limitations that should be underlined in the present study. One of them is having a limited number of cases, the others include short follow up duration and uneven distribution of the lesion sizes.

Conclusion

The findings of this study indicated that calcium silicate-based sealers should definitely be taken into consideration when choosing a material since they have good healing capability on necrotic teeth with periapical lesions. It would be good to do long-term clinical trials with more patients, different diagnoses, and alternative compaction techniques.

Clinical Relevance

Calcium silicate-based sealers appear to be recommended due to their rapid healing time and high healing capability in necrotic cases with periapical lesions.

Conflict of Interest

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

Acknowledgement

None.

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ORIGINAL ARTICLE

Setting time of calcium silicate-based sealers at different acidic pHs

ABSTRACT

Aim: *To evaluate the effect of root canal sealer type (calcium silicate- or epoxy amine resin-based sealer) and solution/pH (acidified or buffered at pH 7.4, 6.4, 5.4, and 4.4) on their setting time.*
Materials and Method: *Samples of BIO-C Sealer (Angelus), EndoSequence BC Sealer (Brasseler), BioRoot RCS (Septodont), and AH Plus Jet (Dentsply) were manufactured into 10-mm internal diameter rings and exposed to gauzes soaked with different solutions (n=6): PBS at pH 7.4 (control), acidified PBS at 6.4, 5.4, and 4.4, as well as butyric acid buffer at pH 6.4, 5.4, and 4.4. The setting time of the sealers was determined when the indentation of a 100-g-weight Gilmore needle was no longer visible on the top surface of the samples (ISO 6876:2012 guidelines). The data were analyzed by a repeated measures analysis of variance (Mixed ANOVA) (α=0.05).*
Results: *All sealers were set within 24 hours. EndoSequence BC Sealer and BioRoot RCS respectively exhibited the longest and the shortest setting times among all sealers and there was a significant difference between them at all solutions/pH (p<0.05); however, their setting time did not significantly vary regardless of solution/pH (p>0.05). The setting time of the BIO-C Sealer significantly increased when exposed to acidified PBS at pH 4.4 (p<0.01), and butyric acid buffer solutions at pH 6.4, 5.4, and 4.4 (p<0.01). The longest setting times observed for BIO-C Sealer were not significantly different from those observed for EndoSequence BC Sealer (p>0.05). The setting time of AH Plus Jet significantly decreased only when exposed to acidified PBS at pH 4.4 (p<0.05).*
Conclusions: *The setting time of only one calcium silicate-based sealer (BIO-C Sealer) was significantly increased when exposed to some acidic pH conditions. Both the shortest (BioRoot RCS) and the longest (EndoSequence BC Sealer) setting times were observed for calcium silicate-based sealers. BioRoot RCS demonstrated the shortest setting time regardless of solutions/pH and seems the most suitable for root canal treatment in acidic environments.*

Cíntia Gasparini Teixeira[1]

Marina Angélica Marciano da Silva[2]

Ana Cristina Padilha Janini[2]

João Daniel Mendonça de Moura[3]*

Daniel Guimarães Pedro Rocha[4]

Rina Andréa Pelegrine[1]

Carlos Eduardo Fontana[5]

Carlos Eduardo da Silveira Bueno[1]

[1]Department of Endodontics, São Leopoldo Mandic Faculty, Institute of Pesquisas São Leopoldo Mandic, Campinas, SP, Brazil.
[2]Department of Restorative Dentistry, Faculty of Dentistry of Piracicaba (FOPUNICAMP), Piracicaba, SP, Brasil.
[3]Department of Endodontics, Federal University of Pará, Belém, Pará, Brazil.
[4]Department of Endodontics, Pontifical Catholic University of Campinas (PUC-Campinas), Campinas, São Paulo, Brazil.
[5]Center for Health Sciences, Pontifical Catholic University of Campinas (PUC-Campinas), Campinas, São Paulo, Brazil.

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Corresponding Author
João Daniel Mendonça de Moura | Faculty of Dentistry, University Center of Pará, Tv. 9 de Janeiro 927, Fátima, Belém PA, Brazil
Phone number: +55 91 98824-7321 E-mail address: joaodanielmoura@gmail.com

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Introduction

Di- and tricalcium silicate-based root canal sealers have shown beneficial effects in endodontics due to their biocompatibility, bioactivity, and stability in moist environments (1, 2); however, dentinal fluid flow can influence the setting reaction and chemically change their surface (1, 3, 4). The setting time of these hydraulic sealers can be negatively affected by the excess moisture and acidic pH of the root canal walls (1, 5). Some manufacturers suggest that the presence of an acidic environment after root canal shaping/instrumentation could delay the hardening of sealers and lead to leakage (6).

The incorporation of additives can alter the physical properties of hydraulic sealers (7, 8). Regarding their presentation, the so-called 'premixed' sealers are supplied in a syringe, in which the product is suspended in a non-aqueous vehicle and requires water from the surroundings to initiate the hydration reaction; in contrast, sealers presented as powder are mixed to a liquid that already contains water to hydrate (1).

Previous studies have investigated the setting time of hydraulic sealers by using different methods (3, 12, 13), moisture concentrations (14, 15), temperatures (16, 17), or residuals of irrigant solutions (18, 19). Although some studies have shown microhardness reduction (20) and solubility increase (21) of some calcium silicate-based sealers exposed to an acidic environment (low pH), there is a lack of studies that investigated their setting time. Therefore, this study aimed to evaluate the effect of root canal sealer type (calcium silicate- or epoxy amine resin-based sealer) and solution/pH (acidified or buffered at pH 7.4, 6.4, 5.4, and 4.4) on their setting time. The null hypotheses tested were that (1) the sealer type and (2) the solution/pH do not significantly affect the setting time of the sealers.

Materials and Method

This study was submitted to the Ethics Committee Research and dispensed under file number 2020-0887.

Preparation of solutions

A commercially available phosphate-buffered saline (PBS) solution at pH 7.4 (Dinâmica Química Contemporânea Ltda) was used as a control. In addition, PBS solution was acidified with butyric acid to obtain solutions at pH 6.4, 5.5, and 4.4, which were verified by using a pH meter (LUCA-210, MS Tecnopon, Piracicaba, SP, Brazil). A buffer solution of butyric acid (0.2 mol/L) and sodium butyrate salt (0.2 mol/L) was also prepared at pH 6.4, 5.4, and 4.4. The concentrations of butyric acid in each solution are shown in Table 1.

Table 1

Butyric acid concentrations (mol/L) in each solution at different pH levels

pH	Acidified PBS* (mol/L)	Butyric acid buffer** (mol/L)
6.4	0.039	0.005
5.4	0.049	0.041
4.4	0.197	0.145

**Acidified with butyric acid. **Buffer solution of butyric acid and sodium butyrate.*

Sample preparation

The hydraulic sealers used to prepare the samples are shown in Table 2. The two premixed sealers (BIO-C Sealer and EndoSequence BC Sealer) were directly dispensed from a ready-to-use syringe. The powder/liquid hydraulic sealer (BioRoot RCS) was prepared over a 10-mm-thick smooth glass plate by mixing a full scoop of powder with 5 drops of the liquid for 60 sec with the aid of a number 24 spatula. An epoxy amine resin-based sealer (AH Plus Jet, Dentsply, Charlotte, NC, USA) supplied as a two-component automix syringe was used as a control

Fifty-four samples of each hydraulic sealer were manufactured by applying the sealers into 1-mm-height and 10-mm-internal diameter plaster rings (Durone type IV, Dentsply) previously immersed in 37 °C distilled water for 24 hours. The 54 samples of the epoxy amine resin-based sealer were manufactured into a 2-mm-height and 10-mm-internal diameter stainless steel rings.

Table 2

Brands, manufacturers, types, composition, presentations, and batch numbers of the sealers

Brand	Manufacturer	Type	Composition	Presentation	Batch no.
BIO-C Sealer	Angelus, Londrina, Brazil)	Portland cement (calcium silicate/ aluminate)	Zirconium, iron, and calcium oxides, silicon dioxide, dispersing agents	Premixed	102198
EndoSequence BC Sealer	Brasseler, Savannah, GA, USA	Tricalcium/ dicalcium silicate	Zirconium oxide, monobasic calcium phosphate, calcium hydroxide, fillers, thickeners	Premixed	20003SP
BioRoot RCS	Septodont, Saint-Maur-des-Fossés, France	Tricalcium silicate	Zirconium oxide, calcium chloride (accelerator), polycarboxylate	Powder/liquid	B25218

The 54 samples of each sealer were exposed to 7 different solutions (n=6): PBS at pH 7.4 (control), acidified PBS at 6.4, 5.4, and 4.4, as well as a butyric acid buffer at pH 6.4, 5.4, and 4.4. The bottom surface of each sample was positioned on a layer of nonwoven fabric, which in turn was placed on two gauzes soaked in 2 ml of the respective solution (22). Then, each sample was stored in a 5-cm-diameter plastic container and covered. The specimens were kept in an oven at 37 °C and 95% humidity, as recommended by the International Organization for Standardization (ISO) 6876:2012 (23).

Setting time

The setting time of the sealers was assessed by following the ISO 6876:2012 guidelines (23). A 100-g-weight Gilmore needle (Odeme Dental Research, Luzerna, Brazil) with a 2-mm-diameter flat active tip was manually held 2 cm above from the top surface of the samples and then released. This procedure was performed at regular intervals of 15 min and the samples were considered set when the needle indentation was no longer visible on the surface. The setting time for each sample was recorded in minutes.

Statistical analysis

The Shapiro-Wilk and Levene tests were respectively used to assess the normal distribution of the data and the sphericity of variances. Then, the setting times of the sealers were analyzed by a repeated measures analysis of variance (Mixed ANOVA) followed by post hoc multiple comparisons between groups with Bonferroni correction (α=0.05) (JASP software version 0.15.0, University of Amsterdam, Amsterdam, Netherlands).

Results

The setting time significantly changed in function of both sealer type and solution pH ($p<0.05$) (Table 3). All samples were found set within 24 hours. All tested sealers exposed to PBS at pH 6.4 showed significantly different setting times ($p<0.05$).
The setting time of both EndoSequence BC Sealer and BioRoot RCS did not significantly vary regardless of solution/pH ($p>0.05$). EndoSequence BC Sealer and BioRoot RCS respectively exhibited the longest and the shortest setting times among all sealers and there was a significant difference between them at all solutions/pH ($p<0.05$). The setting time of BioRoot RCS at the neutral solution (PBS 7.4) was significantly lower than the other sealers ($p<0.05$) (Fig. 1).
The setting time of the BIO-C Sealer significantly increased when exposed to acidified PBS at pH 4.4 ($p<0.01$), and butyric acid buffer solutions at pH 6.4, 5.4, and 4.4 ($p<0.01$). The longest setting times observed for BIO-C Sealer were not significantly different from those observed for EndoSequence BC Sealer ($p>0.05$). The setting time of AH Plus Jet significantly decreased only

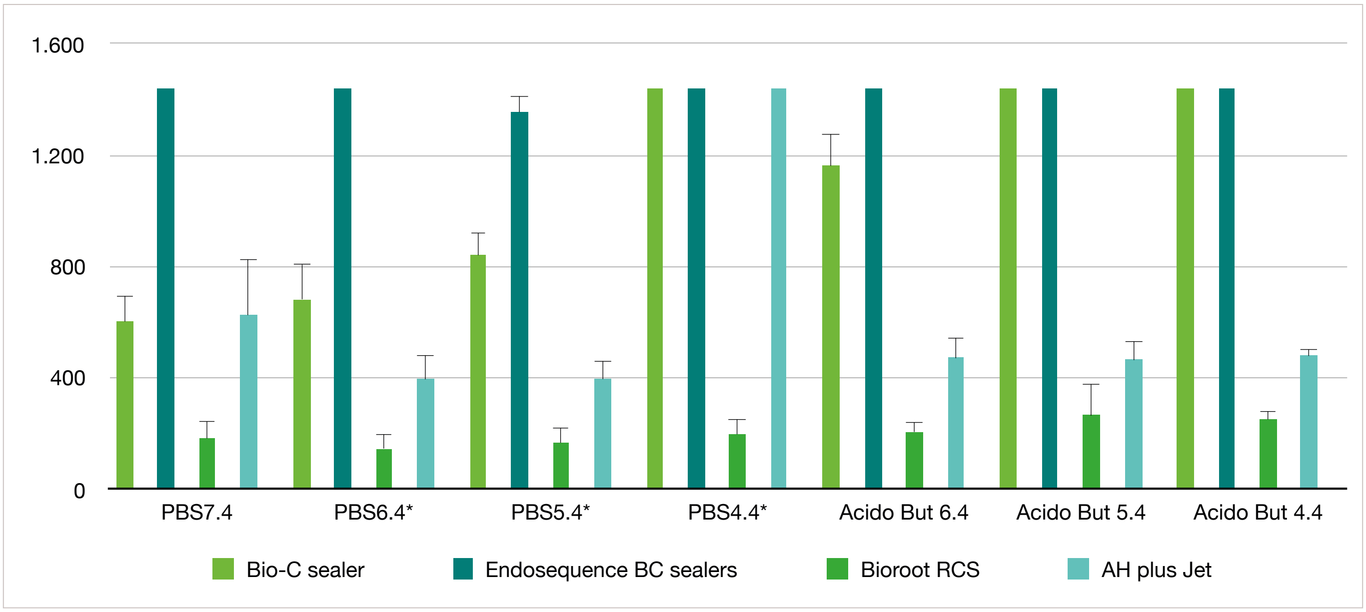

Figure 1
Setting times (min) of sealers exposed to different solutions/pH.
**Solutions without buffer effect.*

when exposed to acidified PBS at pH 4.4 ($p<0.05$).

Except for EndoSequence BC Sealer, the setting times of all sealers tended to increase when exposed to solutions buffered with butyric acid in comparison to acidified PBS solutions at each pH.

Discussion

The acidity of the environment can chemically influence the physical properties and the setting time of calcium silicate-based root canal sealers (8, 20, 24, 25). In this study, the setting time of the sealers significantly varied in function of sealer type and solutions/pH; therefore, null hypotheses had to be rejected.

The evaluation of the setting time of root canal sealers is crucial since prolonged setting times are associated with increased solubility dissolution and disintegration of the sealers, which potentially compromises the sealing integrity of the root canal (26). Moreover, a delayed setting can cause tissue irritation since most root canal sealers ex-

Table 3
Mean (±standard deviations) setting times (min) of the sealers

	PBS	ACIDIFIED PBS*			BUTYRIC ACID BUFFER		
	pH 7.4	pH 6.4*	pH 5.4*	pH 4.4*	pH 6.4	pH 5.4	pH 4.4
BIO-C Sealer	601.33 (±34.70)^{Ba}	683.83 (±47.79)^{Ca}	840.50 (±299.03)^{Ba}	1440.00 (±0)^{Bb}	1166.83 (±423.19)^{Cb}	1440.00 (±0)^{Cb}	1440.00 (±0)^{Cb}
EndoSequence BC Sealer	1440.00 (±0)^{Ca}	1440.00 (±0)^{Da}	1353.00 (±213.11)^{Ca}	1440.00 (±0)^{Ba}	1440.00 (±0)^{Ca}	1440.00 (±0)^{Ca}	1440.00 (±0)^{Ca}
BioRoot RCS	180.50 (±23.05)^{Aa}	143.50 (±19.19)^{Aa}	172.33 (±20.68)^{Aa}	197.50 (±20.45)^{Aa}	206.00 (±13.77)^{Aa}	264.50 (±42.83)^{Aa}	254.17 (±10.98)^{Aa}
AH Plus Jet	631.17 (±74.76)^{Ba}	397.00 (±32.44)^{Ba}	395.67 (±24.48)^{Aa}	1440.00 (±0)^{Bb}	478.33 (±26.94)^{Ba}	466.50 (±25.29)^{Ba}	484.83 (±9.33)^{Ba}

**Solutions without buffer effect. Means with identical superscript uppercase letters in the same columns are not significantly different ($p>0.05$). Means with identical superscript lowercase letters in the same rows are not significantly different ($p>0.05$).*

hibit some level of cytotoxicity before reaching the final setting (14, 27). Ultimately, prolonged setting time may also affect the cementation and lead to the displacement of root canal posts.

Several guidelines have been suggested to replicate clinical conditions on investigations of root canal sealer setting, such as ISO 6876:2012 (11, 28, 29), the American National Standards Institute/American Dental Association (ANSI/ADA) 57:2000, and American Society for Testing and Materials (ASTM) C266-07:2007 (14, 17). Moreover, some studies have assessed the setting time of sealers through rheological tests (18) or experimental models with rats (12). This study used the well-established ISO 6876:2012, which is technically simple and easily reproducible; however, modifications were made to evaluate the sealers under acidic environments.

The bottom surface of the samples was positioned on moistened gauzes to ensure contact between sealers and solutions, as described by Wang et al. (23); however, a layer of nonwoven fabric was positioned in between to prevent the sealer to flow into the gauze fibers and ensure its stability. Each sample was individually stored in plastic containers with covers to ensure the maintenance of particular humid environments provided by different solutions.

Although some studies have used distilled water as a soaking medium (5, 18, 29), other researchers reported different results when compared to PBS (30, 21); thus, PBS at pH 7.4 was used in this study to mimic neutral tissue conditions.

Different from Silva et al. (12) which used pH correctors, PBS was acidified with butyric acid in this study to simulate the acidic environment without potential reactions with other compounds of the sealers (4). Butyric acid is a short-chain fatty acid commonly produced by endodontic pathogens and the most prevalent acid found in endodontic infections (31). Solutions buffered with butyric acid at pH 6.4, 5.4, and 4.4 were also employed for comparative purposes (5, 22).

In addition to pH levels, the concentrations of butyric acid used to prepare the solutions were also taken into account since they can affect the setting time of the sealers. Each sealer sample was exposed to gauzes soaked in 2 ml of solution. This amount was previously determined in a pilot study to avoid excess moisture that could negatively affect the setting of the sealers (14).

According to the manufacturers, the setting times of the tested sealers are 120 to 240 min for BIO-C Sealer, 240 min for EndoSequence BC Sealer, 240 min for BioRoot RCS, and 1440 min for AH Plus Jet.

When exposed to PBS at pH 7.4, the setting time of BioRoot RCS (180.50±3.05) and AH Plus Jet (631.17±74.76) found in this study were within the range indicated by the manufacturers and corroborated previous findings (4, 9, 17, 28); however, the setting times of BIO-C Sealer (601.33±34.70) and EndoSequence BC Sealer (1.440±0) were much longer than those values indicated by the manufacturers and those findings reported by other studies (11, 17, 28, 29). A high moisture level of the medium could delay the initial setting of these premixed sealers suspended in a non-aqueous vehicle (14). Conversely, the powder of BioRoot RCS is mixed with a liquid that already contains the necessary water to initiate the hydration reaction and, might be less affected by excess moisture or acidity (1).

Tricalcium silicate-based sealers such as BioRoot RCS have a faster setting time than dicalcium silicate-based sealers (32). The powder component of BioRoot RCS contains the calcium chloride additive that significantly reduces the setting time and increases the sealer pH at the initial stages due to the release of calcium ions (4, 10, 33). This pH increase during the setting process seems to neutralize acidic environments. Furthermore, the liquid component of the sealer contains polycarboxylate additives, which are known as "superplasticizers" in engineering and allow the reduction in the water: sealer ratio without affecting the setting time; thus, handling of the sealer is facilitated and physical properties are enhanced (34).

The other two hydraulic sealers evaluated in this study have distinct compositions without setting accelerators. EndoSequence BC Sealer contains monobasic calcium phosphate and calcium hydroxide additives, which reduce the release of free calcium and do not neutralize the surrounding environment (8). Conversely, BIO-C Sealer is a Portland cement-based sealer that contains calcium silicates and aluminates. The start of the setting reaction is accelerated since the aluminate phase reacts with water to form ettringites and enhances the sealer strength; however, previous studies have demonstrated that these crystals can be negatively affected by acidic environments (5, 22). Furthermore, BIO-C Sealer contains a silicon dioxide additive that reacts with the calcium hydroxide formed during the setting reaction and leads to the formation of a more hydrated calcium silicate gel. This additive also reduces the release of free calcium and the alkalization of the environment, which may delay the setting reaction, particularly in acidic environments (8). In general, with the exception of EndoSequence BC Sealer which exhibited the longest setting time regardless of the solution and pH, the other sealers exhibited longer setting times when exposed to buffered solutions (PBS at pH 7.4 and butyric acid buffer at pH 6.4, 5.4, and 4.4) in comparison to acidified PBS solutions (at pH 6.4, 5.4, and 4.4) that loss the buffering effect when butyric acid is added. Buffer solutions tend to maintain pH when exposed to acids or strong bases (35).

After setting, the calcium silicate-based sealers exhibited a more brittle appearance than AH Plus Jet. Although considered an important property, the setting time itself does not determine the quality of a root canal sealer (36, 37, 38) since solubility and microhardness are also associated with their stability within the root canals. The excessively slow setting may negatively affect some sealer properties; however, a fast setting does not necessarily indicate superiority in all cases. In this study, the setting time of the BIO-C Sealer was the most influenced by acidic solutions.

Some authors suggest the use of calcium hydroxide or antibiotic pastes to reduce infection/purulent secretion and neutralize the acidity that could negatively affect the setting reaction of root canal sealers (24, 36). The use of sodium hypochlorite solution may resolve this issue since no adverse effect on the setting of AH Plus Jet has been observed (18). However, further studies are needed to better understand the residual chemical effects of these root canal cleaning methods on the setting of calcium silicate-based sealers.

Further research that closely resemble clinical conditions are encouraged to detail the effect of acidic pH conditions and additives contained in hydraulic sealers on their physical properties. Moreover, scanning electron microscopy and energy dispersive spectroscopy could provide insights into potential surface changes and chemical characterization of these materials.

Conclusions

The setting time of only one calcium silicate-based sealer (BIO-C Sealer) was significantly increased when exposed to some acidic pH conditions. Both the shortest (BioRoot RCS) and the longest (EndoSequence BC Sealer) setting times were observed for calcium silicate-based sealers. BioRoot RCS demonstrated the shortest setting time regardless of solutions/pH and seems the most suitable for root canal treatment in acidic environments.

Clinical Relevance

Understanding the setting time of root canal sealers in various pH conditions is crucial for dental professionals during endodontic procedures. These insights can aid clinicians in selecting the most appropriate sealer for specific clinical scenarios, ultimately contributing to the success and efficiency of endodontic procedures.

Conflict of Interest

The authors declare no conflicts of interest related to this study.

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ORIGINAL ARTICLE

Influence of the type of post and the cementation line on the adhesive union of fiberglass posts within the root canal

ABSTRACT

Aim: *To evaluate the adhesive strength of fiberglass posts cemented in the root canal, according to the type of post and the thickness of the cement line.*
Methodology: *Forty primary bovine incisors, 17 mm long, were endodontically treated. After seven days, the teeth were unfilled and prepared to receive the 13 mm posts. The roots were randomly divided into four groups according to the type of post (Reforpost® cylindrical post and Exacto® conical post) and the thickness of the cementation line. The posts were cemented with RelyX U200® within the root canal. The roots were sectioned, thus obtaining specimens with an average thickness of 1.92 mm in each of the root thirds (cervical and middle). The specimens were submitted to the push-out test. After performing the test, the fractured samples were analyzed under a stereomicroscope to determine the fracture pattern. The data obtained were treated by the one-way ANOVA test, followed by the Tukey test, and the non-parametric t test (α=0.05).*
Results: *There was a statistical difference between the groups regarding the different root positions analyzed (P<0.05). The Exacto® conical post demonstrated the best results when used with a diameter matching that of the prepared root canal. Conversely, the least favorable outcome was observed when the Reforpost® cylindrical post was employed within a root canal prepared with a diameter larger than that of the post.*
Conclusions: *The type of post and the thickness of the cementation line influence the displacement resistance of intraradicular cemented fiberglass posts. The smooth conical post with a small cement line showed greater adhesive bond strength.*

Gabriela Carvalho da Rosa[1]

Gabriella Gulden Lobo[1]

Vicente Castelo Branco Leitune[2]

Tiago André Fontoura de Melo[3*]

[1]Dentistry College, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil.

[2]Dental Materials Division, Department of Conservative Dentistry, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil.

[3]Endodontic Division, Department of Conservative Dentistry, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil.

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Corresponding Author
Tiago André Fontoura de Melo | Universidade Federal do Rio Grande do Sul, Faculty of Odontology
Dept. of Conservative Odontology, Porto Alegre, RS | Brazil
E-mail: tiago.melo@ufrgs.br Phone: +55 (51) 3308-5430

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Introduction

In certain clinical cases, restoring endodontically treated teeth poses a significant challenge in clinical practice due to extensive tissue loss. In situations where the crown structure is insufficient, the placement of an intraradical post becomes necessary to enhance the retention of the restorative material (1).
In this context, the use of fiberglass-based retainers has gained widespread acceptance (2) due to their advantages over cast metal cores. These advantages include improved aesthetics, elimination of labor-intensive laboratory steps, reduced number and duration of clinical sessions, as well as mechanical properties that closely resemble dentin. This similarity promotes a biomechanical behavior akin to natural teeth, thereby reducing the risk of coronal fractures (3, 4). However, a limitation associated with fiberglass posts is that their shape may sometimes fail to adapt to the root canal's morphology, resulting in a thick and irregular cementation line (5).
The most common issues encountered with prefabricated posts involve loss of retention and subsequent detachment from the root canal (6). During the adhesive cementation of intraradical posts, the greater the discrepancy between the canal diameter and the post diameter, the higher the levels of residual stresses due to the increased volume of cement (7-9). According to D'Arcangelo et al (10), the ideal thickness of the cement line between root dentin and post should fall within the range of 0.1 to 0.3 mm, a finding supported by Grandini et al (11). A narrower cementation line not only enhances the stability of the intraradical post within the root canal (12) but also reduces the concentration of polymerization stress on the cement layer (13), thereby increasing bond strength (14).
Consequently, this study aims to assess whether the type of post and the thickness of the cementation line have an impact on the resistance to displacement of fiberglass posts cemented intraradicularly. The null hypothesis posits that neither the type of post nor the thickness of the cementation line influence the bond strength of fiberglass posts with intraradicular dentin.

Methodology

Sample selection and preparation
Forty primary bovine incisors were selected and standardized to the initial apical diameter of the root canal, equivalent to a K-type #20 endodontic instrument (Dentsply/Maillefer Instruments S.A., Ballaigues, Switzerland). The root canals had circular sections. After cleaning, the dental crowns were sectioned at the cementoenamel junction with the aid of a low-speed silicone carbide disc. The length of the root remnant was standardized to 17 mm and the working length (WL) was 1 mm below this standardized measurement (WL=16 mm).

Endodontic preparation of samples
All samples were prepared manually with first and second series K-type stainless steel endodontic instruments (Dentsply/ Maillefer Instruments S.A., Ballaigues, Switzerland). Chemomechanical preparation was carried out in the following sequence of K-type instruments: #20, #25, #30, #35, #40, and #45 (Dentsply/Maillefer Instruments S.A., Ballaigues, Switzerland). All instruments were used along the WL.
At each instrument change, the canals were irrigated with the aid of a plastic syringe (BD Solumed, Sao Paulo, SP, Brazil) and 25 mm 30-gauge NaviTip needles (Ultradent, Indaiatuba, SP, Brazil), containing 2.5% sodium hypochlorite (Iodontec Industria e Comercio de Produtos Odontologicas Ltda., Porto Alegre, RS, Brazil) in a standard amount of 2 mL. After the preparation, the final toilet was made with 17% trisodium EDTA (Biodinamica, Ibipora, PR, Brazil) for three minutes and with agitation of #45 instrument. The canals were then washed with distilled water (Iodontosul, Industrial Odontologica do Sul LTDA, Porto Alegre, RS, Brazil) and dried with absorbent paper points (Tanari Industria Ltda., Manaus, AM, Brazil).
For the endodontic filling, the canals were filled with gutta-percha cones and AH Plus® epoxy resin-based cement (Dentsply/ Maillefer Instruments SA, Ballaigues, Switzerland), using Tagger's hybrid technique and #60 McSpadden® compactor (Dentsply/Maillefer Instruments SA, Ballaigues, Switzerland).

After filling, all samples were provisionally restored with Cimpat® restorative material (Septodont, Saint Maur des Fosses, France) and immersed for two days in a flask containing distilled water, at 37 °C and 100% relative humidity, for complete setting of the endodontic sealer.

Division of experimental groups

The teeth were divided into four experimental groups (Table 1) by the simple random sampling using Excel (Microsoft Excel, Microsoft, USA).

Post cementation and specimen preparation

The canals were cleared to prepare the space needed for the post to be cemented. The root canal filling was removed along 13 mm, leaving 3 mm of apical sealing.
In the canals of the GR and GE groups, drills from the kit with a diameter equivalent to the post to be cemented in the root canal were used. In the teeth of the GRM and GEM groups, drills from the kit with a larger number than the post to be cemented were used, thus providing a greater cementation line. The choice of the diameter of the posts was made according to the conditions of the treated canal, based on the guide ruler for selecting the posts provided by the manufacturer.
After performing the unobturation of the canals, the posts underwent the cementation protocol, following the manufacturer's recommendations. The posts were disinfected with 70% alcohol (Icarai, Sao Paulo, SP, Brazil) prior to use and subsequently dried. Single Bond Universal® adhesive was applied for 20 seconds and then dried with air jets for 5 seconds.
The posts were luted with self-adhesive cement (RelyX U200R, 3M ESPE, St. Paul, MN, USA). The resin cement was applied to the root canal with the aid of a centrix syringe (DFL, Rio de Janeiro, RJ, Brazil) with a fine metal tip. The post was inserted into the root canal and filled with cement to the most coronal portion to hermetically seal the entrance and photoactivated with the aid of an EC450 device (ECEL, Ribeirao Preto, SP, Brazil), with light intensity greater than 400 mW/cm^2, for 20 seconds, and chemical polymerization for 6 minutes.
After 15 days of cementation and storage in distilled water, the roots were sectioned perpendicularly to the long axis, and two thick slices (1.92 mm±0.32 mm) were obtained with the aid of a cutting machine (Labcut 1010, Extec Corp., Enfield, CT, USA). The slices were obtained in a standardized manner at 5 mm (cervical third), and 10 mm (middle third) away from the cervical edge of the root (Figure 1), identified, and stored in an oven at 37°C and 100% relative humidity for 7 days.

Push-out test

The specimens were placed on a stainless steel metal support with a 2 mm central hole. Given the conical shape of the posts, the load was applied in the apical-cervical direction from the apical surface, so that the post could be pushed towards the widest portion of the root canal.
The load was applied only on the post surface with a tip of approximately 1 mm in diameter coupled to the EZ-SX (Shimadzu Corp., Kyoto, Kyoto, Japan) universal testing machine. The selected load cell was 500 kg (50 N) and the loading speed was 0.5 mm/min. The values were recorded in N and displacement resistance in MPa.
To measure the area of the canal and calculate resistance, the diameter of the upper and lower circle of the canal and the thickness of the section (area of a cone trunk) were measured (15). After the push-out test, the fractured specimens were analyzed under an X20 stereomicroscope (Stemi 2000, Karl Zeiss, Germany) to determine the adhesive, cohesive, or mixed failure pattern.

Statistical analysis

The Shapiro-Wilk test was used to assess the normality of the data. One-way ANOVA test, followed by the Tukey test, and the non-parametric t-test were used to assess bond strength. The level of significance was set at 5% ($P \leq 0.05$). Statistical analysis was performed using GraphPad Prism 7 (GraphPad Software Inc., San Diego, CA, USA).

Table 1
Experimental groups

Group	n	Intraradicular post type	Drill diameter in relation to the post
GR	10	Pino Reforpost®	Equal
GRM	10	Pino Reforpost®	Bigger
GE	10	Pino Exacto®	Equal
GEM	10	Pino Exacto®	Bigger

Results

Mean values of displacement resistance (MPa) for the different experimental groups in different regions of the canal are shown in Table 2. There was a statistical difference between the groups regarding the different root positions analyzed (P<0.05). Among the different groups, the GE group, which employed a conical post with a diameter matching that of the prepared root canal, exhibited the most favorable outcomes compared to the other groups. It is worth noting that there was no discernible distinction between the GEM and GR groups in terms of their results. The least favorable outcome was observed in the GRM group, which utilized a cylindrical post within a root canal that had been prepared with a diameter larger than that of the post.

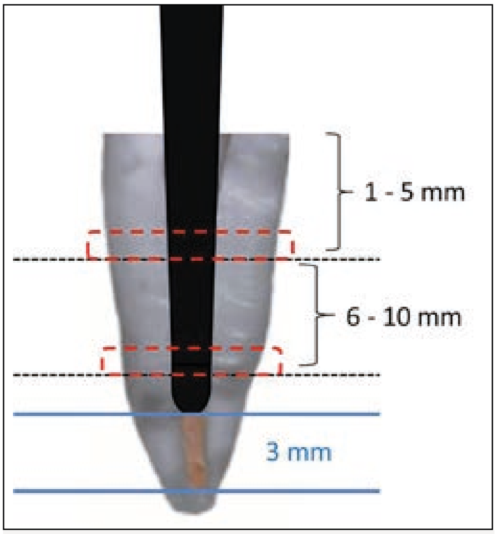

Figure 1
Schematic diagram of root slices.

The most notable findings regarding resistance to displacement were observed in the cervical third of the canal, in comparison to the middle third, when examining each group individually. However, it's worth noting that an exception was identified in the GE group, where no significant difference was observed between the two root thirds.
Graph in figure 2 show the percentage of failures in the samples in the cervical and middle thirds of the root. There was an increase in adhesive failures in the GRM and GEM groups compared to the other tested groups. Cohesive failures predominated in the GR, GE and GEM groups

Discussion

The use of fiberglass posts in weakened roots or in large root canals is a challenge, since the prefabricated post has a standardized size, and many times there is no size that allows its complete adaptation to the root canal walls, requiring thus a thick layer of cement in some regions of the canal that can cause failures in the cementation process.
Fiberglass posts are composed of longitudinal fibers surrounded by a resin-based matrix (16), which in a way favors the adhesive cementation process. Thus, resin cements with chemical, photopolymerizable, or dual polymerization mechanisms are routinely used for cementation of this type of post (17).
Shear strength depends on the degree and stability of micromechanical locking and chemical adhesion between root canal dentin, bonding agent and fiberglass post. The push-out test is based on the shear stress at the interface between the dentin and the cement, as well as between the post and the cement (18). The main advantage of push-out testing over other bonding testing methods is the ability to test a material within a dentin-surrounded canal, thus reproducing the clinical use of the material (19).
In the analysis of the adhesive union between the tested experimental groups, better results can be observed with the use of conical posts in relation to the cylindrical ones, as well as the influence of the thickness of the cementation line. In the groups in which the cementation line was less thick, there was a greater adhesive bond strength between the post and the

Table 2
Bond strength in root segments in the push-out test

Experimental Group	Root thirds		P
	Cervical	Middle	
	MPa (±SD)	MPa (±SD)	
GR	11.69Ba±(2.07)	9.17BCb±(2.27)	P<0.05
GRM	9.56Ca±(1.74)	7.02Cb±(2.28)	P<0.05
GE	16.92^{Aa}±(4.82)	12.92^{Aa}±(4.19)	P=0.062
GEM	13.58^{Ba}±(1.40)	10.53^{ABb}±(2.40)	P<0.05
P	P<0.05	P<0.05	

Means followed by different uppercase letters in the column differ significantly in the analysis of variance and means followed by different lowercase letters in the row differ significantly in the non-parametric t-tests, at a significance level of 5%.

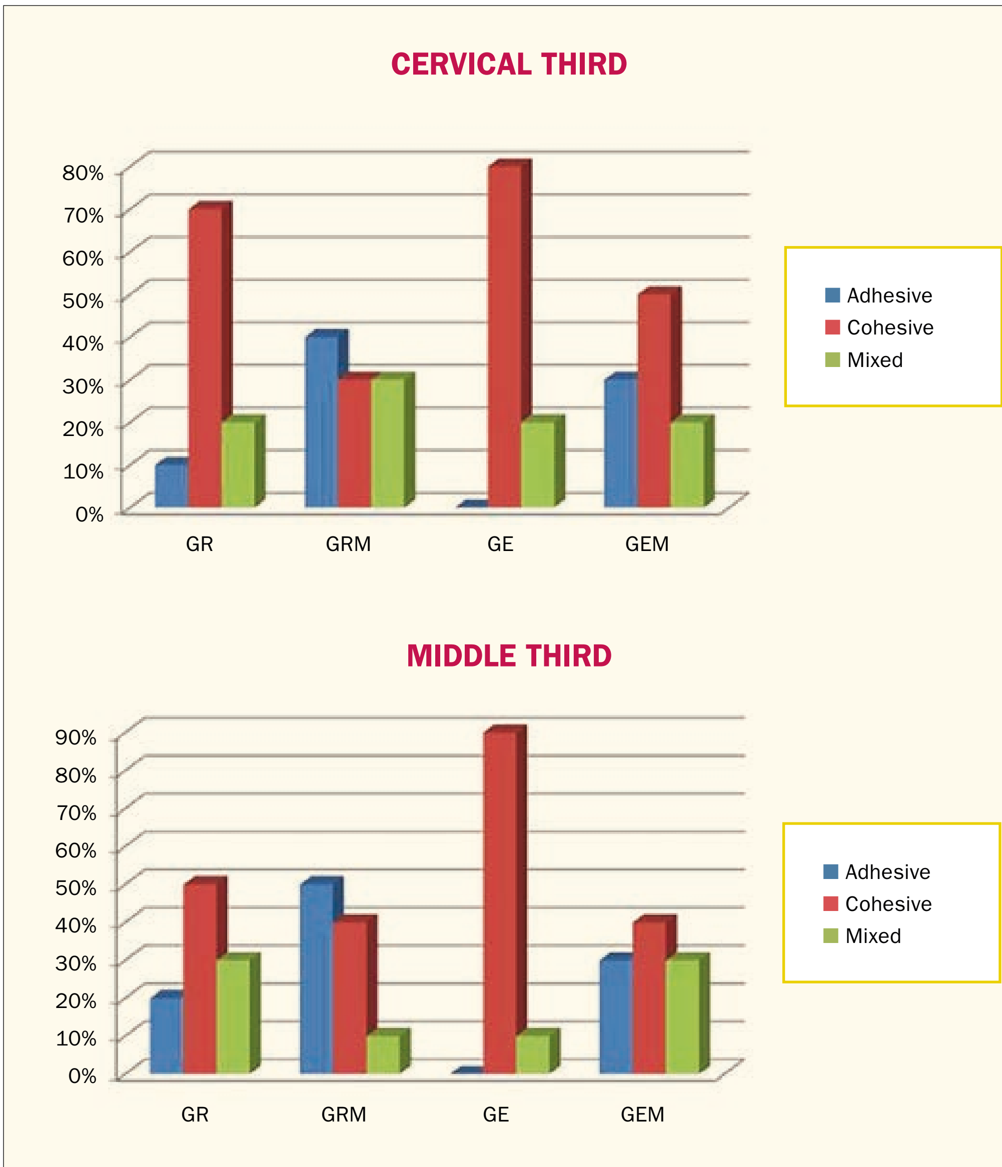

Figure 2
Failure patterns (%) after tested protocols.

dentin wall. This corroborates the statement that the bond strength of the fiberglass post to the dentin is significantly lower when the resin cement layer is thicker (20, 21). Thick layers of cement decrease bond strength, as a greater volume of cement leads to greater retraction, generating greater tension at the adhesive interface, which causes greater formation of cracks and bubbles within the root canal (22). Greater thickness, as a function of the C factor, maximizes polymerization contraction (23, 24) and results in empty spaces, and gaps (25). Well-fitting posts and thin layers of resin cement are essential to provide good adhesion to root dentin (26). However, several laboratory studies involving push-and-pull tests have reported divergent results regarding the impact of cement thickness on the bond strength to intraradicular surfaces (27-29).

In the study by Rengo et al (30), it can be observed that the volume of the post space and the volume of the post itself were considered smaller for oval posts when compared to circular posts. However, the cement volume was greater in oval posts, regardless of the level of the post space. Munhoz et al (31) also found no significant difference in the portion of the post space occupied by oval and circular posts. It is believed that selecting the type of post to be used according to the diameter of the root canal and the use of preparation drills, which are included in the manufacturer-recommended kits, may potentially provide greater control over the cement line around the post.

Analyzing the results of adhesive bonding between the thirds, a trend towards better bond strength results was observed in the cervical third compared to the middle third, which was also observed in the study by Borges et al (32). This observed difference may be due to factors such as dentin morphology and the diameter and number of dentinal tubules between the thirds. It is known that the number and diameter of dentinal tubules decreases in the cervico-apical direction. In addition to these factors, the adhesion process using resin cements depends on the formation of the hybrid layer. According to Calixto et al (33), this hybridization becomes more critical as it moves towards the apical third of the canal due to the difficulty in establishing adhesion in this region.

The resin-dentin interrelationship, an area called the hybrid layer, plays a fundamental role in micromechanical retention (34). The adhesive interface is expected to form a firm and permanent connection between the dentin and the resin cement (35). However, the formation of the hybrid layer consists of the infiltration of adhesive monomers into the collagen fiber network resulting from acid demineralization and subsequent polymerization, and is directly related to the treatment of the substrate surface (34). The hybrid layer is a highly organic interface, relatively hydrophobic and acid-fast. However, regardless of the system or material used, layer formation is not always homogeneous and stable (35).

The predominant type of failure observed in the study was cohesive, but with an increase in adhesive failures in the groups in which the root canal had a larger diameter in relation to the post. Aleisa et al (36) also found in their study more cohesive failures when the appropriate post space was created with the same drill size as the post size.

Conclusions

The adhesive bond strength of intraradicular fiberglass posts cemented was influenced by the type of post and the thickness of the cement line. The smooth conical post with a small cement line showed greater adhesive bond strength.

Clinical Relevance

The type of post and the cementation line influence intraradicular adhesion.

Conflict of Interest

The authors declares that there is no conflict of interest.

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ORIGINAL ARTICLE

Triple antibiotic paste versus nano calcium hydroxide as an intracanal medicament in human primary molars: a randomized clinical trial

ABSTRACT

Aim: *Intracanal medicaments play a critical role in cleaning microbial biofilm, dentin tubule sterilization, and successful endodontic treatment. This study aimed to evaluate the antibacterial effect of Nano-calcium hydroxide (NCH) and Triple Antibiotic Paste (TAP) as intra-canal medicaments in human non-vital primary molar teeth.*

Methodology: *The NCH particles were characterized by transmission electron microscopy (TEM), Fourier transform infrared (FTIR) spectroscopy, and X-ray diffraction (XRD). This study included 39 primary molar teeth with an indication for non-vital pulp therapy. Following the access cavity preparation, a microbial sample (S_1) of each tooth was collected and canals were prepared by chemo-mechanical technique. Using dynamic block randomization, canals were divided into three groups based on the type of medicament. The second microbial sample (S_2) was collected 7 days after ICM application. The canal's aerobic and anaerobic micro-organisms load was calculated by counting colony-forming units (CFUs).*

Results*: The TEM, FTIR, and XRD characterization techniques confirm the NCH nanoparticle formation. NCH showed a reduction of the number of aerobic and anaerobic micro-organisms by 98.09% and 90.79%, respectively. While TAP had greater antibacterial activity compared to NCH aerobic (99.95%) and anaerobic (99.78%) micro-organisms. NCH and TAP showed a statistically significant difference (P<0.005) in bacterial elimination of the root canals in comparison with chemo-mechanical irrigation alone.*

Conclusion: *Both TAP and NCH antibacterial activity were approved during the endodontic.*

Ahmad Gholami[1,2,3]

Khatereh Asadi[1,3,4]

Nazafarin Samiraninezhad[1,5]

Dordaneh Ghaffaripour[5]

Azam Safari[1]

Abbas Abbaszadegan[6]

Yasamin Ghahramani[6*]

[1]Biotechnology Research Center, Shiraz University of Medical Sciences, Shiraz, Iran
[2]Department of Pharmaceutical Biotechnology, School of Pharmacy, Shiraz University of Medical Sciences, Shiraz, Iran
[3]Department of Medical Nanotechnology, School of Advanced Medical Science and Technology, Shiraz University of Medical Sciences, Shiraz, Iran
[4]Guilan Road Trauma Research Center, Guilan University of Medical Sciences, Rasht, Iran
[5]Department of Pediatric Dentistry, School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran.
[6]Department of Endodontics, School of Dentistry, Shiraz University of Medical Sciences, Shiraz, Iran.

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Corresponding Author
Yasamin Ghahramani | Department of Endodontics, School of Dentistry, Shiraz University of Medical Sciences, Ghasrdasht Street, Shiraz, 71956-15878 | Iran.
Email: ghahramani.yas@gmail.com Phone: +98 711 3426739

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Introduction

Primary teeth play a critical role in maintaining proper occlusion and the development of the oral cavity (1). The invasion of microorganisms and their toxins, which are mainly bacterial products, into dental tissue is a common clinical problem in primary teeth (2). Infectious may lead to inflammation, abscesses, cysts, apical granulomas, dissolution of tooth tissue, oral lesions, and even osteomyelitis (3, 4). Retaining primary teeth requires successful endodontic treatment that relies on cleaning and disinfecting microbial biofilm in the root canal system and preventing the proliferation and reentry of bacteria in the root canal system (5, 6).

Among the various kinds of intracanal medicaments, the triple antibiotic paste (TAP) and conventional calcium hydroxide (CH) are commonly used intracanal medicaments for endodontic treatment. One such medication is TAP, which contains three antibiotics including permanent metronidazole, ciprofloxacin, and minocycline. TAP can be successfully applied to disinfect canals and treat periapical pathology. However, this approach's restrictions are the development of antimicrobial resistance and tooth discoloration (7-9). CH ($Ca(OH)_2$) with a size range from 1 to 10 µm, is the "Gold Standard" endodontic medicament to control residual bacteria in the prepared canal that has strong antimicrobial activity. CH damages the bacterial cytoplasmic membrane and DNA. However, some microorganisms resist to CH (10). To overcome this, minimizing the CH particle diameter and forming CH nanoparticles may have been sought to improve the eradication of bacteria. Nano-calcium hydroxide (NCH) should possess a higher surface-to-volume ratio with their greater interaction in dentinal tubules which results in remarkable improvement in antibacterial and antifungal properties, long-lasting effects, deep tissue penetration, and effective prevention of coronal microleakage (11, 12).

Numerous in vitro and clinical studies have assessed the efficacy of different intracanal medicaments in reducing bacterial infections in teeth. Calcium hydroxide (CH) has been found to reduce bacterial colony counts, particularly *Enterococcus faecalis* (*E.faecalis*) when used alone or in combination with chlorhexidine or TAP (13, 14). TAP and CH have been shown to improve the development of pulp dentin complex and disinfect immature teeth (15). Various studies compared the antimicrobial efficacy of TAP and CH. In a study TAP showed a slightly stronger antimicrobial efficacy against *E. faecalis*, compared to CH; however, the difference wasn't statistically significant (16). Another study showed that both TAP and CH reduced initial intracanal bacterial loads, and exhibited similar levels of bacterial reduction (17). However, there are studies suggesting that TAP compared to CH had a significantly better effect on eliminating *E. faecalis* from dentinal tubules and decreasing bacterial biofilm formation (18-20). Furthermore, in a previous study, the group treated with NCH showed superior antimicrobial activity and penetration of dentinal tubules versus the group treated with conventional CH (21).

Despite the importance of understanding the bacterial load in primary teeth root canals before and after intracanal medicament application, there is currently limited literature on this topic. This study aimed to address a gap in current research by focusing on the antimicrobial effectiveness of TAP and NCH in primary teeth. While prior studies have examined the antimicrobial properties of TAP and CH, most have focused on permanent teeth. Additionally, our study employed a nano-sized calcium hydroxide (NCH) formulation to explore the potential benefits of nanotechnology in dental materials. Therefore, this study aimed to assess the total count of aerobic and anaerobic bacteria in primary teeth root canals that require non-vital pulp therapy, both before and after the application of NCH and TAP intra-canal medicaments.

Materials and Methods

Study design

This randomized double-blinded controlled trial aimed to evaluate the efficacy of TAP and CH in decreasing the bacterial load of infected primary molars in children. This study was approved by the ethical committee of Shiraz University of Medical Sciences with the ethical code number of IR.SUMS.REC.1397.828 and clinical trial code of IRCT-20181226042132NI.

Participants

Participants with maxillary or mandibular primary molars with pulpal infection admitted to the endodontic ward of the faculty of dentistry clinic, Shiraz, Iran between December 2021 and June 2022 were included in this study. Participants (n=39) ages (4-6 years old) with infected maxillary or mandibular primary molars, considering a two-tailed significance level of 5% and 80% power. Exposure of the pulp with caries and fistula was determined in clinical diagnosis. Teeth with internal or external root resorption and excessive mobility as well as those with involvement of permanent dental follicles were excluded. Participants with a history of taking antibiotics for at least 1 week before the study were excluded. Written acquired consent was obtained from the parents of participants.

Randomization and Blinding

The patients were randomly assigned to three groups (each 13) according to a dynamic randomized block design. To reduce the influence of age-related variables, thirteen blocks each containing three participants with similar ages were created. Participants were randomly assigned to each treatment group. Randomization was performed with the help of an assistant. A random code number was assigned to each patient at the beginning of the study to maintain blinding. Participants were blinded to their group allocation. The operator who conducted and analyzed the microbial tests was completely unaware of the group allocations.

Intervention

- Intracanal medicament preparation

To prepare TAP, a combination of ciprofloxacin (Bayer plc, UK), metronidazole (Flagyl, Winthrop Pharmaceuticals, UK), and minocycline (Expanscience Laboratories, Paris, France) was mixed at a concentration of 20 mg/ml for each antibiotic. NCH was prepared following the procedure. A total of 100 mL sodium hydroxide (0.4 M) was added gently to the same volume of calcium nitrate dehydrate (0.4 M) on a magnetic stirrer at ambient temperature for an hour. Then, the precipitate was filtered and washed three times with distilled water. Afterward, the resulting white precipitate was placed in a container under ambient argon gas and the temperature was gradually increased to 60°C (at the rate of 1 °C/min) for 120 min. The final precipitate was maintained in a vacuum desiccator until used in the clinical trial.

- Characterization of nano-calcium hydroxide (NCH)

The size and morphology of NCH were accessed using transmission electron microscopy (TEM ZIESS machine, model EM10C, German). The spectral compatibility and chemical structure of NCH were evaluated by Fourier transform infrared (FT-IR) spectroscope (PerkinElmer, Spectrum RXI). The FT-IR spectrum was recorded in the range of 400–4000 cm-1using the KBR technique. The XRD pattern of the crystallinity and phase of NCH were carried out at ambient temperature using an X-ray diffractometer (PW 1710 BASED. Philips, the Netherlands) with Cu-Kα radiation at a wavelength of 1.54 Å and scanning rate of 1 step/s (scan size: 0.1°/step).

- Intracanal medicament administration and Microbial sample collection

The access cavity was prepared under local anesthesia (2% lidocaine, Darupakhsh, Tehran, Iran) with a high-speed handpiece and diamond burs. The standard endodontic procedure was performed under rubber-dam isolation. The pulp chamber was opened and the pulp tissue was carefully removed using hand instruments. Orifices of the larger-sized canal (distal in mandibular molars and palatal in maxillary molars) were extended by a Neolix orifice opener (NEOLIX, Châtres-la-Forêt, France). First microbiological samples (S1) were collected by inserting #20 sterile absorbable paper points (Ariadent

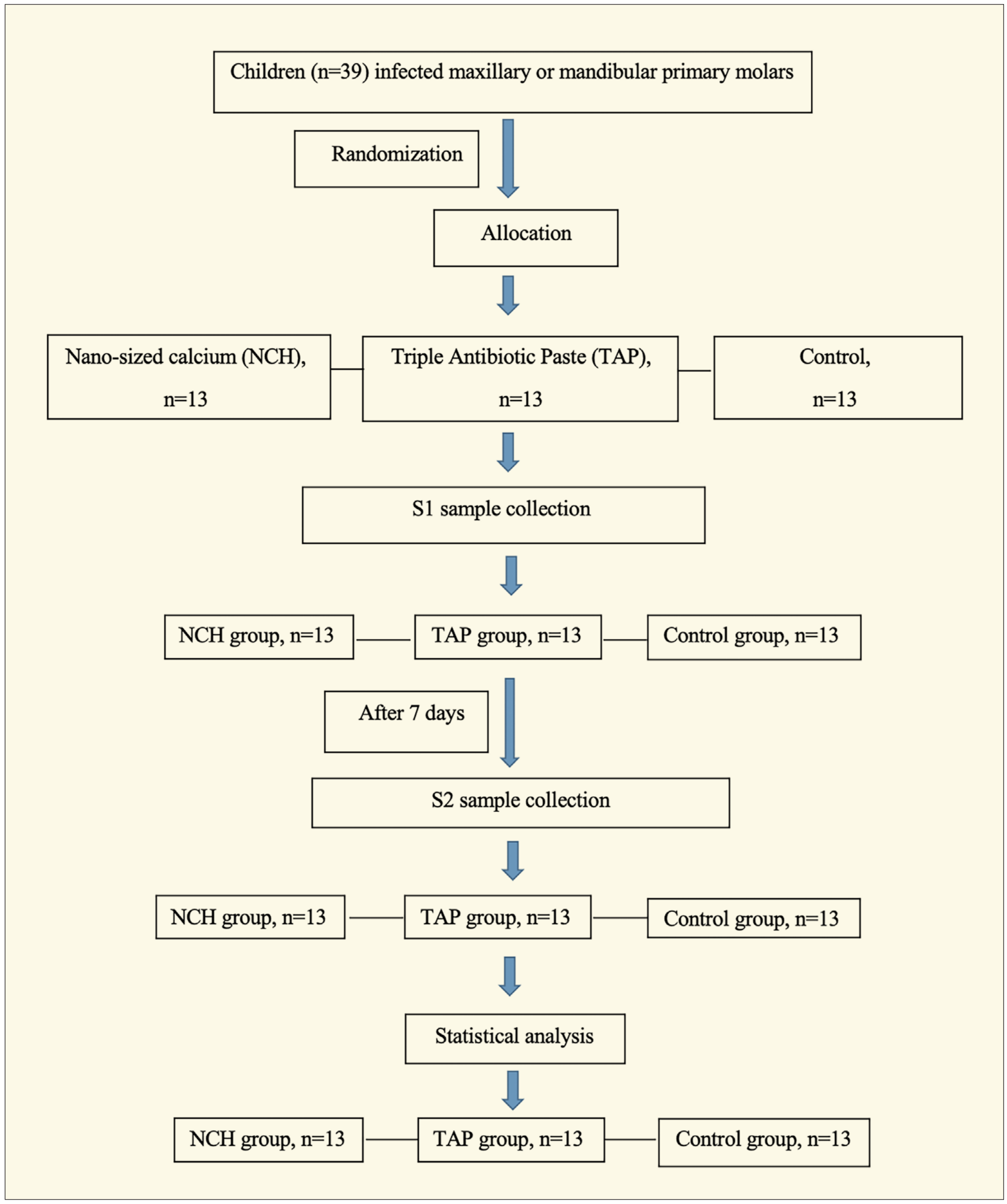


Figure 1
Diagram of the clinical procedure of the study.

Co., Tehran, Iran), after the extension of the canal, (leaving it for about 30 seconds and then transferring it into a test tube containing 2 ml brain heart infusion). The canals were then completely prepared with K- files #20,25 (Mani, Tochigi, China) and rinsed with normal saline.

After mechanical preparation, the canals were dried with sterile paper points. Subsequently, the teeth were divided into three groups in terms of receiving intracanal medicament. The TAP group received TAP, the NCH group received NCH, and the control group received rinsing with normal saline (NaCl 0.9%, Darupakhsh, Tehran, Iran).

The medicaments were applied in root canals, using lentulo spiral#25 (Dentsply Maillefer, Ballaigues, Switzerland), and the cavity was temporarily sealed with reinforced ZnOE (Kemdent, England). Seven days later, the temporary restoration was removed and the canal was irrigated with normal saline to wash out the medicaments. Second bacteriological samples (S2) were collected after the total removal of medicament residues. Then canals were obturated with Metapex (Meta Biomed Co. Ltd., South Korea), and the teeth were permanently restored with glass ionomer cement (GC Fuji IX, GC, Tokyo, Japan) followed by cementation of stainless-steel crown (3M, St. Paul, MN, USA). Figure 1 displays the diagram of the clinical procedure.

Microbiological procedures

The microbial procedure by Donyavi et al. (13) was performed in this study. A total of 1 mL of thioglycolate (for anaerobes) and 1 mL of Brain Heart Infusion (BHI, Merck, Darmstadt, Germany) broth (for aerobic bacteria) transfer mediums were used for each paper point to be immersed in and then transferred to the lab within 30 min for further analysis.

A total of 1, 2, 5, and 10 µL of each medium (thioglycolate and BHI) were collected by a sampler and immersed in 1 mL of their respective medium type. Next, 10 µL from each tube was extracted and transferred to a plate containing the mentioned medium. The collected samples from the thioglycolate and BHI medium were cultured on the Brucella agar enriched with defibrinated sheep blood and blood agar, respectively. Brucella agar plates were placed in an anaerobic jar. Using, an anaerobic environment was produced by a Gas-pak, and the jar was incubated at 37 ˚C for 72 h. Blood agar plates were also incubated at 37 ˚C for 24 h for aerobic bacteria to proliferate. Following the incubation period, plates were removed from the incubator, and formed colonies were counted by a colony counter. The mean number of colony-forming units (CFU) was reported based on the concentration of primary dilution. In addition, the percentage of reduction in the number of aerobic and anaerobic colonies was calculated for each group and reported.

Statistical analysis

Data were analyzed using SPSS software (SPSS version 26.0, SPSS, Chicago, IL, USA). Descriptive statistics were reported using mean and standard deviation. One-sample Kolmogorov-Smirnov test was used to assess the normality of the data. Kruskal-Wallis and Mann-Whitney U tests were used for group comparison. $P \leq 0.05$ was considered the statistical significance value.

Results

Nano-calcium hydroxide (NCH) characterization

An electron microscope (TEM) was used to evaluate the NCH particle's size, shape, and crystalline degree. Figure 2 (b) shows that NCH particles are randomly oriented and irregularly structured with a variable number of sides, but more resemble hexagons. The mean diameter of fabricated nanoparticles was 35.44±12 nanometers (nm), which shows the histogram of the synthesis NCH in Figure 2 (c). Moreover, many NCH with particle sizes below 40 nm and larger than 60 nm are very few.

FT-IR Spectroscopy related to the chemical structure of synthesized NCH mentioned in Figure 3 was applied to confirm the presence of both hydroxide and carbonate parts of calcium. FT-IR spectra of the NCH illustrated that the band at 3642 cm^{-1} belongs to OH stretching mode. The OH stretching absorption peak was relatively broad (3250 to 3530 cm^{-1}) and showed that hexagonal calcium hydroxide phase with a mixture of phases. The sharp 879 cm^{-1} peak is related to the ν_2 symmetric deformation, the 712 cm^{-1} peak for the ν_4 bending vibration, and the 1453 cm^{-1} is related to the ν_3 asymmetric stretching of the CO3 group. The minor peaks at 2501–2531 and 1788 cm^{-1} were due to the adsorption of the atmospheric CO2 and C=O stretching, respectively.

Figure 4 shows the XRD pattern of NCH particles. NCH showed strong peaks at 29.1, 34.2, 47, 50.5, 54.6, 62.7, 70.6, and 84° in the 2θ regions and these peaks corresponding to the (100), (101), (102), (110), (111), (200), (201), (202), and (211) planes of the hexagonal NCH phase.

Microbial tests

Children (n=39) aged 4-6 with infected maxillary or mandibular primary molars were included in the study. As shown in

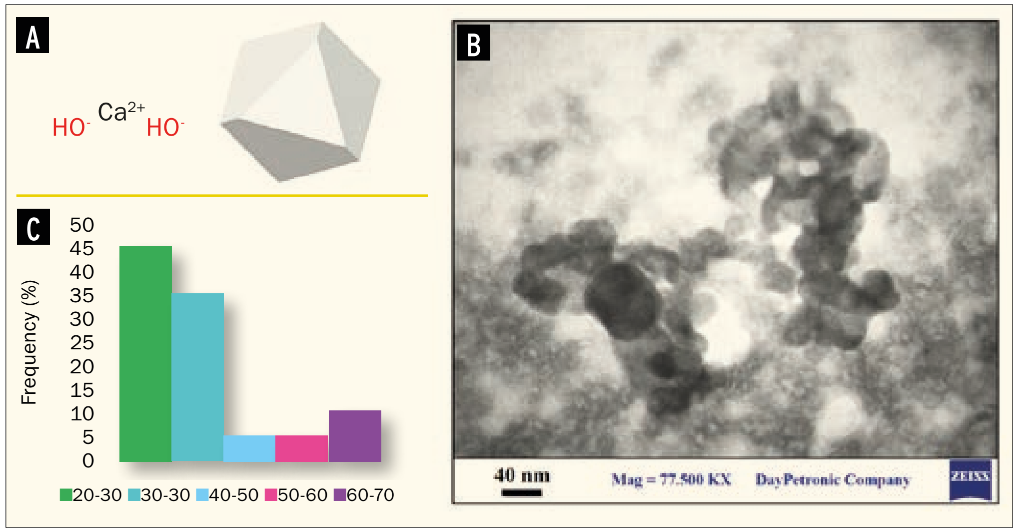


Figure 2
A) Chemical structure and schematic of calcium hydroxide nanoparticle (NCH) **B)** TEM image of NCH on the scale of 40 nm, **C)** histogram of nanoparticle diameter size distribution obtained from microstructure measurement software.

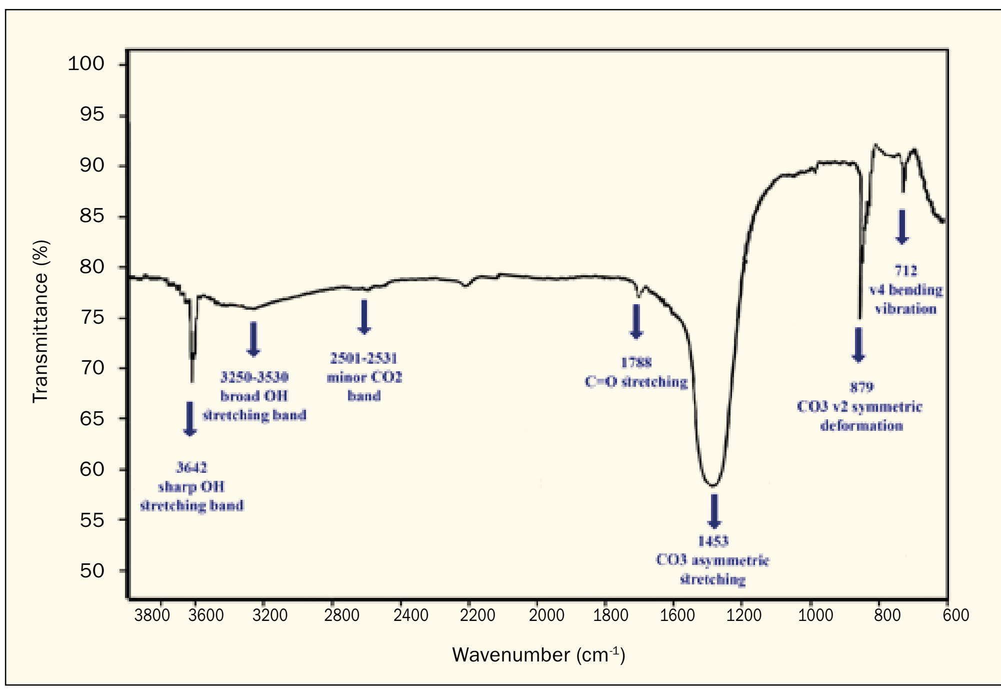


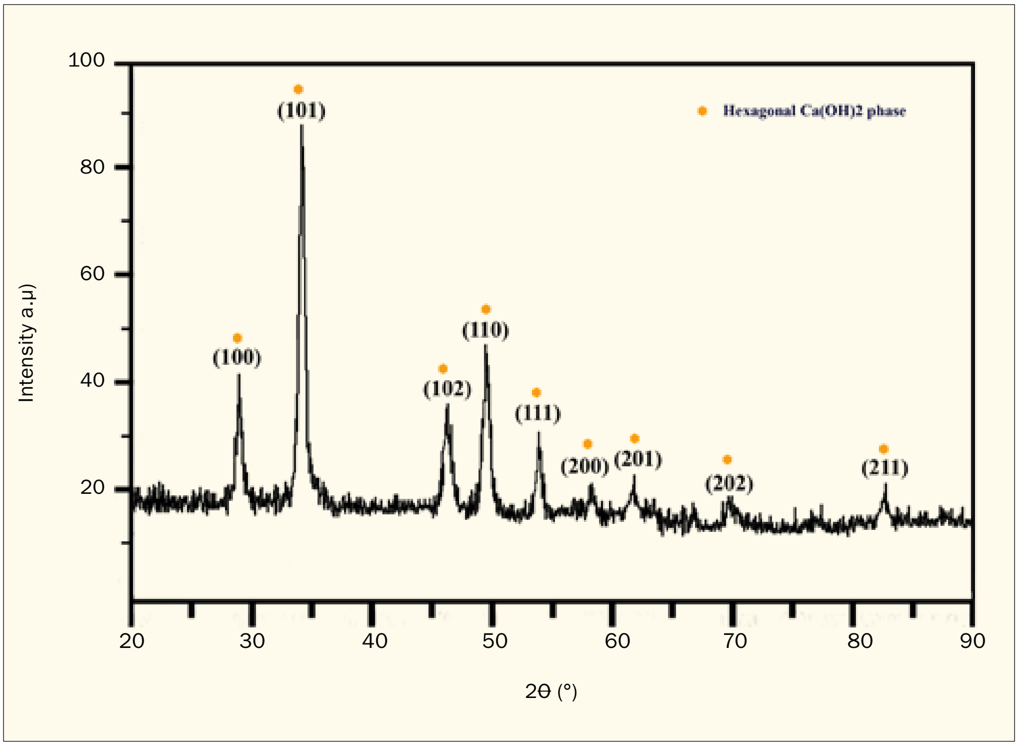
Figure 3
FT-IR spectra of NCH.

Table 1, the results demonstrated a significant reduction in the number of aerobic and anaerobic bacteria after the application of TAP (P-value<0.01) and NCH (P-value<0.01) compared to the control group. The mean reduction in the number of aerobic bacteria was 99.95% (±0.06) for TAP and 98.05% (±2.36) for NCH. The mean reduction in the number of anaerobic bacteria was 99.78% (±0.24) for TAP and 90.79% (±11.69) for NCH. The data suggests that TAP was significantly more effective than NCH in reducing the number of aerobic and anaerobic bacteria (P-value<0.01). Table 2 demonstrated that TAP had more potential in reducing the number of aerobic and anaerobic CFUs compared to NCH.

Discussion

The characterization of synthesis particles using TEM, FTIR, and XRD demonstrated the NCH formation in the present work. Moreover, the effectiveness of TAP and NCH as intracanal medicaments to reduce the number of aerobic and anaerobic mi-

Figure 4
XRD spectra of NCH.



cro-organisms in maxillary and mandibular primary molars over seven days was approved. However, our result showed that TAP had more potential in reducing the number of aerobic and anaerobic CFUs compared to NCH. As pulpal infection is a complex microbial process, evaluation of both aerobic and anaerobic bacteria in the root canals was deemed critical (22). Although chemo-mechanical debridement of the root canals reduces up to 53% of intracanal micro-organisms, the use of intracanal medicaments is essential to achieve more effective eradication of micro-organisms (14, 23, 24). This is especially crucial in primary teeth due to their ribbon-shaped canal anatomy and the presence of deeply penetrated bacteria in the dentinal tubules (14, 25).

The comparison of CFU counts before and after the application of TAP and NCH showed a significant reduction in the number of CFUs. The average aerobic bacterial CFUs before intracanal medicament application in TAP, NCH, and control groups were 4.7×10^4, 4.07×10^4, and 6.77×10^4, respectively. These measurements for anaerobic bacteria were 1.29×10^5, 4.31×10^4, and 1.02×10^5. The present study's CFU results on primary teeth align with previous studies, indicating that overall anaerobic CFU was higher than aerobic CFU and ranged between 10^2 to 10^8 (13, 26, 27). The application of NCH and TAP resulted in a significant reduction in both aerobic and anaerobic bacteria; and, TAP showed a higher reduction percentage compared to NCH. Results of the present study demonstrated a 98.09% and 90.79% significant reduction in aerobic and anaerobic bacteria, respectively, when applying NCH. In comparison, TAP showed a reduction of the number of aerobic and anaerobic micro-organisms by 99.95% and 99.78%, respectively. TAP used as intracanal medicaments, has shown to be more effective in reducing the number of CFUs, as the mean CFUs that remained after one-week application of TAP were 8 and 60.8 for aerobic and anaerobic CFUs, respectively. Other studies have also reported the efficacy of TAP in reducing total bacterial count and in treating primary teeth with pulpal exposure with poor prognosis (14, 28-31). Alfadda et al. investigated the antibacterial properties of triple TAP and CH

Table 1

Sample distribution, mean ± standard deviation, and percentage of reduction for aerobic and anaerobic micro-organisms before and after medicament application

	Before ICM Application (CFU/mL) mean± SD			After ICM Application (CFU/mL) mean± SD			Percentage of reduction mean± SD		
	TAP	NCH	Control	TAP	NCH	Control	TAP	NCH	Control
Aerobic bacteria	4.70 (±0.4) $\times10^4$	4.07 (±0.49) $\times10^4$	5.77 (±0.06) $\times10^4$	8.00 (±0.18)	3.36 (±0.53) $\times10^2$	4.48 (±0.38) $\times 10^4$	99.95 (±0.0)	98.05 (±2.36)	24.05 (±4.59)
p values	N.S*	N.S	N.S	0.00	0.00	0.00	0.00	0.00	0.00
Anaerobic bacteria	1.31 (±0.8) $\times10^5$	1.29 (±0.52) $\times10^5$	1.02 (±0.60) $\times10^5$	6.08 (±0.73) $\times10^1$	1.43 (±0.90) $\times10^3$	0.64 (±0.70) $\times10^5$	99.78 (±0.2)	90.79 (±1.69)	29.39 (±5.40)
p values	N.S	N.S	N.S	0.00	0.00	0.00	0.00	0.00	0.00

**N.S means Not Significant*

Table 2

The p values of the Mann-Whitney U test from the comparison of each two groups and the level of significance regarding the Mann-Whitney U test

Groups	Aerobic Before ICM application	Aerobic After ICM application	Anaerobic Before ICM application	Anaerobic After ICM application	Percent reduction of Aerobics	Percent reduction of Anaerobics
TAP and Control	0.72	0.00	0.45	0.00	0.00	0.00
NCH and Control	0.38	0.00	0.41	0.00	0.00	0.00
TAP and NCH	0.35	0.00	0.73	0.00	0.00	0.00

in root canals infected with *E. faecalis* biofilm. There was no significant difference between TAP and CH in the level of bacterial reduction, and they both improved viability and alkaline phosphatase activity in dental pulp stem cells on dentin surfaces (17). Dewi et al. determined the most effective concentrations of TAP and CH for complete eradication of *E. faecalis* within dentinal tubules. They reported that TAP at 10 mg mL^{-1} effectively eliminated bacteria, while CH was not successful in eradicating *E. faecalis* (20).

However, many in vitro and in vivo studies showed TAP few drawbacks such as human periodontal ligament fibroblasts cytotoxicity and notable inflammatory reactions in subcutaneous connective tissue. Furthermore, several studies showed overusing antibiotics such as TAP leads to the development of Antibiotic-resistant bacteria and antibiotic-resistant genes (32-34). Several studies have suggested that CH may not be effective against bacteria, particularly *E. faecalis*, but the nano form of CH improves its efficacy through greater penetration into the dentinal tubule depth compared to conventional CH. NCH showed a superior mean penetration depth at all coronal, middle, and apical dentin levels. Subsequently, nanoparticles' unique chemical and physical properties such as small dimensions and the highest surface area/mass ratio could be the fact behind the greater deep penetration, antibacterial activity, and long-lasting effects of NCH particles (35, 36). Recent studies also have supported this and showed that probable NCH particle agglomeration drawback was eliminated by combining with using high-intensity focused ultrasound (HIFU) to deliver in dentin tubules (37). Furthermore, an ex vivo study suggested the replacement of NCH as intracanal medicaments for the preservation of the root canal and dentin structure. They observed that CH could significantly reduce dentin microhardness in comparison with NCH, while NCH leads to any alteration in the microhardness value after 4 weeks (38).

Conclusion

Considering the total count of aerobic and anaerobic bacteria in primary tooth root canals, both TAP and NCH are more effective in reducing the number of CFUs during the endodontic treatment for a week. Moreover, no statistically significant difference was observed between the antibacterial activity of TAP and NCH. As regards, TAP use limitations such as antibiotic side effects and antimicrobial resistance, NCH could be a promising alternative to the treatment of primary teeth with pulpal infections. Further clinical trial studies with larger sample sizes are required to evaluate the long-term effects of this medicament on primary teeth and its efficacy in treating specific bacterial strains.

Clinical Relevance

Nano Calcium Hydroxide can be considered as an Intracanal Medicament in Human Primary Molars.

Declaration

Ethics approval

All procedures performed in this study followed the ethical standards of the institutional thesis research committee (Shiraz University of Medical Sciences IR.SUMS.REC.1397.828 and the randomized clinical trial was approved by the following code; (IRCT Code: IRCT20181226042132NI) and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Conflict of Interest

The authors declare that they have no competing interests.

Acknowledgment

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ORIGINAL ARTICLE

Comparative evaluation of smear layer removal with Ultra-X device and XP-Endo Finisher file system: an ex-vivo study

ABSTRACT

Aim: *Chemo-mechanical debridement plays a crucial role in root canal treatment. Irrigant activation is the final step before obturation and it helps in effectively cleansing and disinfecting the complex root canal system. The current study aimed at comparing the smear layer removal after activation with Ultra-X and XP-Endo finisher (XPEF).*

Methodology: *Sixty extracted single-rooted second premolars were collected. The specimens were decoronated until 13mm standard length and were shaped using Protaper gold rotary files to size 40 under standard irrigation protocol. Following this, based on the final activation, the specimens were randomly allocated to: group 1: Conventional Needle Irrigation (CNI) (n=20); (Control group), group 2: Activation using Ultra X Ultrasonic device (PUI) (n=20); group 3: Activation using XPEF (n=20). Finally, the specimens were examined for smear and debris removal using scanning electron microscopy (SEM).*

Results: *Tested groups showed significant differences (p<0.05) in debris and smear layer removal when compared to control. However, no difference (p>0.05) was elicited between groups 2 and 3.*

Conclusion: *Both Ultra-X and XPEF devices showed comparable debris and smear layer removal.*

Raghavendra Penukonda[1]

Kavalipurapu Venkata Teja[2]

Kranthi Raja Kacharaju[1]

Sia Yin Xuan[1]

Deeviya A/P Mohan[1]

Lau Yi Sheun[1]

Mariangela Cernera[3]

Flavia Iacculli[3]

[1]Department of Endodontics, Faculty of Dentistry, MAHSA University, Bandar Saujana Putra, Malaysia.
[2]Department of Conservative Dentistry and Endodontics, Mamata Institute of Dental Sceinces, Hyderabad, Telangana State, India.
[3]Department of Neuroscience, Reproductive and Odontostomotological Sciences, University of Naples, Federico II, Italy.

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Corresponding Author
Raghavendra Penukonda
Department of Endodontics, Faculty of Dentistry, MAHSA University, Bandar Saujana Putra, 42610, Selangor, Malaysia.

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Introduction

The root canals are shaped adequately by mechanical instrumentation and cleaned and disinfected appropriately by root canal irrigants (1). After the mechanical shaping with rotary Ni-Ti instruments, the actual irrigation process helps in effectively cleansing and flushing inorganic and organic tissue debris from the root canal space (2). Conventional needle irrigation (CNI) is a commonly and widely employed method of irrigant delivery while performing root canal therapy (3). According to previous research, the CNI is ineffective at removing debris and smear layer from canal complexities (4). As a result, clinicians are increasingly shifting towards machine-assisted irrigation activation techniques.

Literature also states the inefficiency of the irrigant activation devices in completely removing the smear layer and debris from the root canal system (5). There is also literature claiming the inefficiency of the instruments in achieving the three-dimensional wall contact with the root canal system (6). Even the recently claimed XP-Endo shapers could not achieve completely clean canals after usage (7). As far as the literature is concerned, the study results claim the inefficiency of minimal root canal shaping in obtaining adequate root canal debridement (8). Hence, the real benefit of the final activation protocol can be better investigated after conventional root canal shaping with appropriate instruments to appropriate sizes. So considering all these facts, in the current study, the efficacy of recently introduced and less investigated Ultra-X, an ultrasonic activation device, and XP Endo finisher (XPEF) in prepared single rooted premolars was compared. Although laboratory studies are still unclear on the efficacy of using XPEF on obtaining the canal cleanliness after root canal shaping (9), there is no literature comparing the efficacy of using Ultra-X with XPEF. Hence, the present study, assessed the superiority of these modalities after complete root canal shaping in terms of smear layer removal from root canals activated with Ultra X and XPEF.

Mathodology

The institutional ethical committee approval (RMC/ECO2/2023) for the current study was obtained from the university-affiliated hospital before the research commencement. The sample size for the current study was calculated based on the previous research (10). Based on the sample size calculation, a total sample of 57 was achieved at an effect size of 0.42 and power 80%. One sample in each group was increased to compensate for the sample loss, finally achieving a sample size of 20 per each group ($1-\beta=80\%$, $\alpha=0.05$). PRILE guidelines were followed for drafting the study (11).

Following this, 60 freshly extracted human mandibular second premolars were collected. The premolars were obtained from the oral surgery department. The teeth were rendered clean by rinsing under running tap water, and hard tissue deposits were removed using an ultrasonic scaler (Selector U2 Piezo Scaler, Apoza, Taiwan, China). The soft tissue deposits were removed by immersing the teeth in 3% NaOCl (Clorox, Household Cleaning Products of Egypt, Cairo, Egypt) for 20 minutes before being manually scaled. Finally, the teeth were radiographed, and the root curvatures were determined by applying the Schneider technique.

Inclusion criteria

- Mandibular second premolars exhibiting single root with type I Vertucci canal configuration and closed apex.
- Teeth extracted for orthodontic or periodontal purposes from patients aged between 20 to 30 years.
- Canal curvature preferably less than 10 degrees

Exclusion criteria
• Teeth with surface cracks and extensive decay
• Teeth with resorption or calcifications
• Formerly endodontically-treated teeth

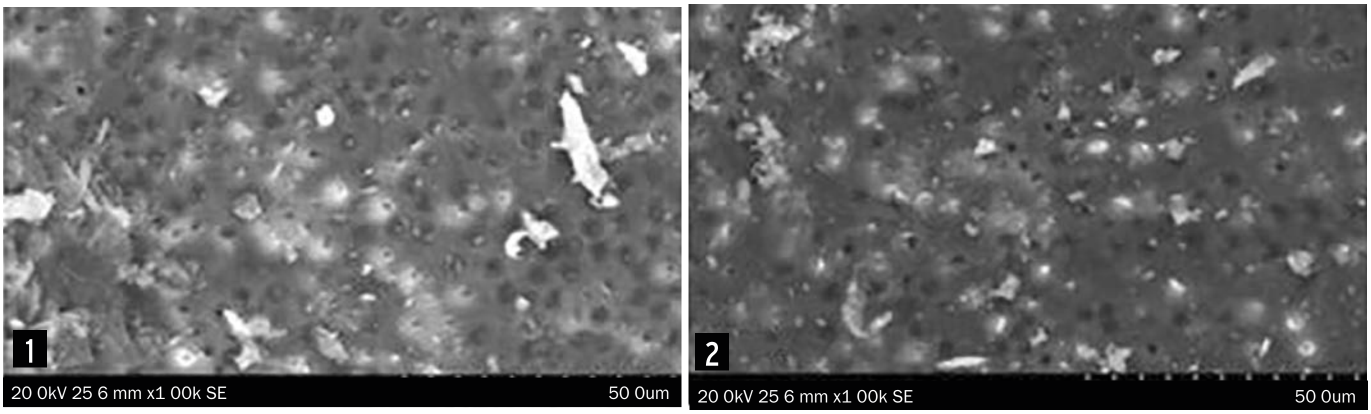
The teeth were preserved in 10% of formalin (El Fath, Cairo, Egypt) until use. Later the teeth were decoronated to a standard root length of 13 mm using a slow-speed diamond disc and water spray. The access cavity was refined if necessary using an Endo Z bur (Dentsply Maillefer, Switzerland) mounted onto a high-speed handpiece. The working length (WL) was approximated 1 mm short of the standardized root length (12 mm). The access cavity preparation and the WL determination procedure were performed by a postgraduate who was not aware of the protocol and not involved in the study. Later the instrumentation was performed by a single operator. He was instructed on the instrumentation and the specific irrigation protocols. The specimens were then prepared using Protaper gold Ni-Ti rotary files (Dentsply Maillefer, Ballaigues, Switzerland). The coronal root portion was enlarged using an orifice opener, and later the canals were prepared up to the F4 rotary instrument using the manufacturer's recommended torque and speed. 5 ml of 5.25% NaOCl (Parcan, Septodont, France) was used to irrigate the root canals between the instruments by placing a 30-gauge flexible polypropylene plastic side vented irrigation needle (Irriflex, PD, Switzerland), 1mm short of WL. The teeth were randomly assigned (www.random.org) to the operator by a head nurse. The specimens were assigned to three groups (n=20) depending on the final irrigation activation technique.

Group 1: Conventional Needle Irrigation (CNI) (n=20) (Control group, fig. 1-3).
Group 2: Activation using Ultra X Ultrasonic device (PUI, fig. 4-6) (n=20).
Group 3: Activation using XPEF, fig. 7-9 (n=20).

CNI control group: The final root canal irrigation was completed with a volume of 20 ml of 5.25% warm NaOCl at 37 °C by inserting a side vented irrigation needle (Irriflex, PD, Switzerland), 1 mm away from the WL and slowly irrigating the solution using an in and out motion. After irrigation with warm 5.25% NaOCl, 5 ml of 17 % EDTA (MD Cleanser, MetaBiomed, South Korea) was irrigated slowly for 1 min. About 10 ml of normal saline was employed as an intermediate solution and a final rinse. The canals were rendered dry using absorbent paper points.

PUI Using Ultra X: To standardize the study conditions with the XPEF group, 10 ml of warm 5.25% NaOCl at 37°C was irrigated into the canal and ultrasonically activated by placing the tip of the Ultra X, 1 mm short of the WL for 30 seconds. The ultrasonic tip was moved in and out motion during irrigant activation. The canal was then irrigated with 10 ml warmed 5.25% NaOCl and activated for 30 seconds using the same technique. Following this, 5 ml of 17% EDTA was irrigated over 1 min slowly into the root canal and activated for 30 seconds by adopting the same method mentioned above. 10 ml of normal saline was used as an intermediate solution for final flushing. The total activation time was 90 seconds, and 20 ml of warmed 5.25% NaOCl and 5 ml of 17% EDTA were used intermittently to standardize the volume of NaOCl and EDTA used in the other groups. The canals were dried using absorbent paper points.

XPEF Group: The XPEF (size 25, taper 0.00) with an endomotor was used to clean the canals in this group with settings of 800 rpm and torque 1 Ncm. To simulate the clinical conditions in which the XPEF instrument is present in the austenitic phase with its unique sickle shape. The root canal was filled with 5.25% NaOCl to 37 °C. XPEF was operated as recommended by the manufacturers for the entire WL. The XPEF was used in a slow up-and-down motion for 30 seconds within the canal.



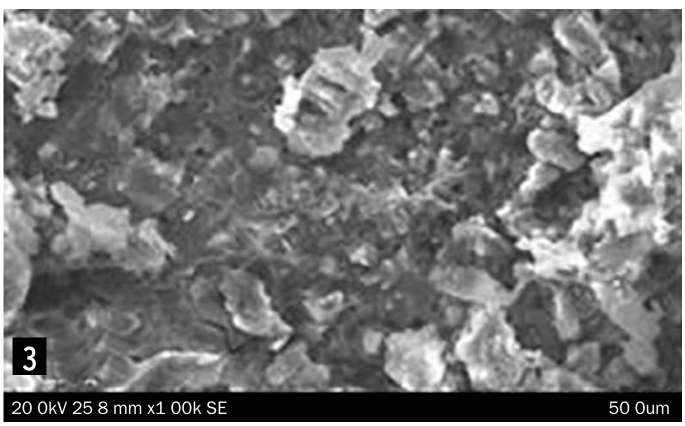


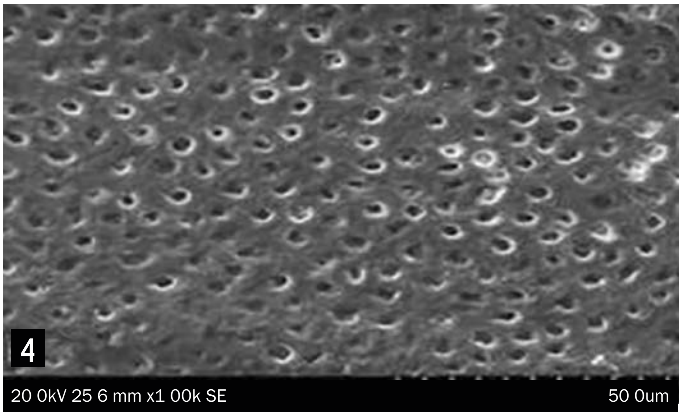
Figure 1-3
Depicting the coronal, middle and apical sections of control group.

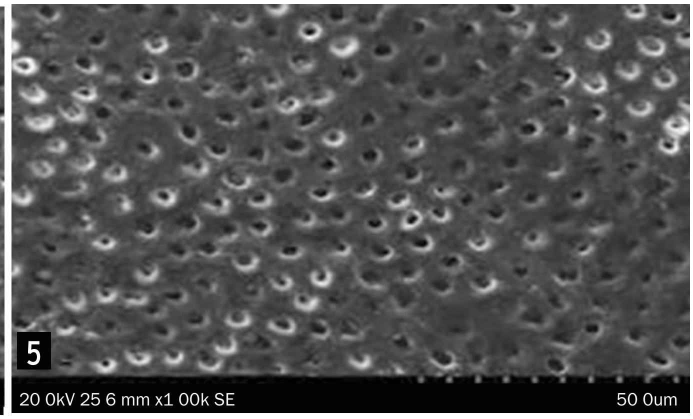
The canal was then irrigated with 10 ml of warmed 5.25% NaOCl, and XPEF was activated for 30 seconds by adopting the same technique, followed by another 10 ml of warmed 5.25% NaOCl flush. Subsequently, about 5 ml of 17% EDTA was irrigated over 1 min slowly into the root canal and activated using XPEF. Again about 10ml of normal saline was used as an intermediate solution and final flush. The total activation time was 90 seconds, and 20 ml of warmed 5.25% NaOCl and 5 ml of 17% EDTA were used intermittently. Paper points were used to dry the canal.

Longitudinal grooves were carefully placed on the buccal and lingual root surfaces by not cutting through the canal. The roots were then separated with a chisel and mallet, and one-half was chosen for interpretation. The specimens were then sputtered with gold (K550X sputter coater, Quorum Technologies, Lewes, UK) and examined by Scanning Electron Microscopy (SEM) (Model Quanta, FEI, Eindhoven, Netherlands) at 30 kV and a magnification of 1000 X. The images were captured from the centre of about 11 mm (Coronal), 7mm (Middle), and 3 mm (Apical) from the apex (Figures 1, 2, 3). Two researchers evaluated the images, and the

Table 1
Samples scored according to the smear layer's presence or absence in the coronal, middle, and apical portions of the roots. Statistical significance among the different groups was reported.

Score	Control				XPEF (XP Endo Finisher)				Ultra X (PUI)			
	Coronal	Middle	Apical	P-value	Coronal	Middle	Apical	P-value	Coronal	Middle	Apical	P-value
1	7	0	0	0.041*	15	15	11	0.001*	15	13	5	0.002*
2	8	8	3		0	0	4		0	2	10	
3	0	7	12		0	0	0		0	0	0	
Total	15	15	15		15	15	15		15	15	15	





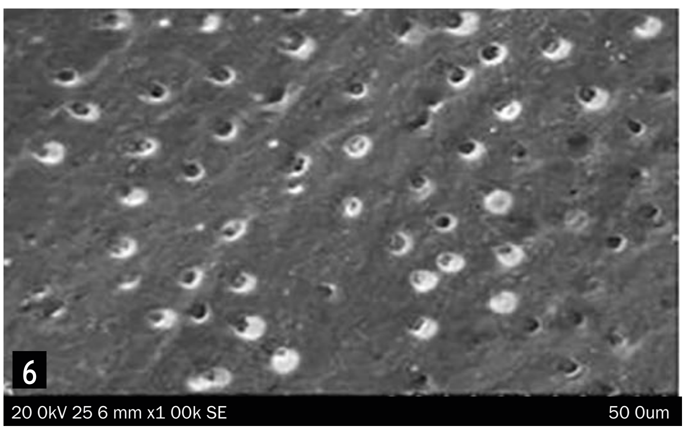


Figure 4-6
Depicting the coronal, middle and apical sections of XPFE group.

scoring was done. The specimens were scored according to the smear layer's presence or absence from the root canals' coronal, middle, and apical portions using the Torabinejad et al. criteria (12) as follows:

1. No to minimal smear layer, all tubules were clean and open;
2. Moderate smear layer: No smear layer on the root canal surface, but tubules with debris;
3. Heavy smear layer on the root canal surface and tubules.

The resulting scores were tabulated, and statistical analysis was performed.

Statistical analysis

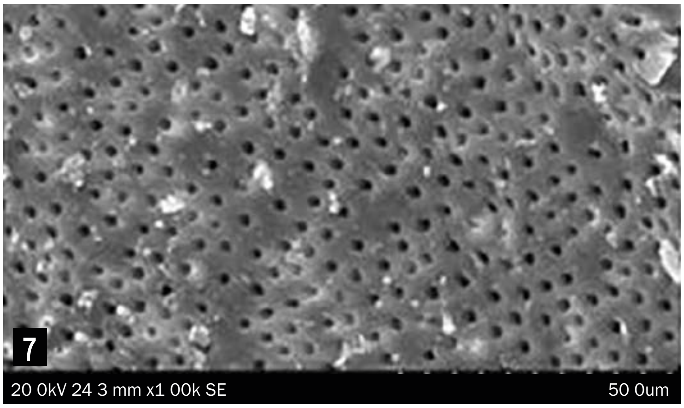
The obtained data were analysed using the chi-square test in SPSS software version 22.00. Statistical significance was set at p=0.05.

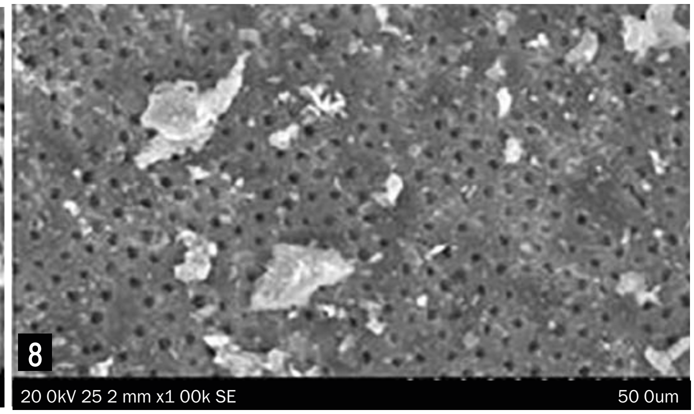
Results

The results of smear layer removal were tabulated in Table 1. A significant difference in the smear layer and debris removal was observed ($p<0.05$) among test groups when compared to control. However, no significant difference ($p>0.05$) between the experimental groups (group 2 and 3) was observed.

Discussion

The current study results showed no significant difference in irrigants activation using PUI Using Ultra X or XPEF. However, both the experimental groups have shown to be better at removing the smear and debris than the CNI group. A previous systematic review literature including laboratory studies showed unclear evidence on the superiority of PUI compared to the XPEF (9), corroborating the results obtained by the present study. Although in the current study the canals were enlarged to size 40 and 0.06 taper, the recent research data on XP endo shaper usage proved no improvement in canal cleanliness on increasing the apical width to the specified sizes as the present study employed (13). The specimens' apical size of 40 and 0.06 taper was choosen according to previous literature as an acceptable master apical file size and taper in obtaining better root canal debridement (14). In addition, warmed 5.25% NaOCL at a temperature of 37 °C as a primary irrigant for the final activation protocol was used, considering the improved flexibility and change in allow transitions of XPEF at body temperatures (15, 16). On the contrary, previous study results reported the efficiency of 60 °C heated NaOCL in conjunc-





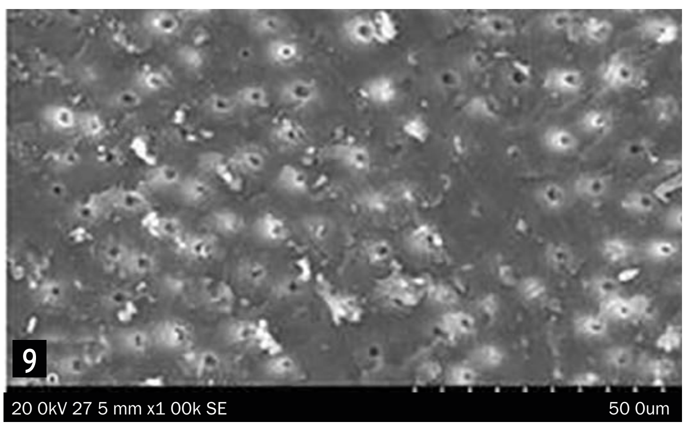


Figure 7-9
Depicting the coronal, middle and apical sections of PUI group.

tion with 17% EDTA to be effective in the removal of the smear layer, even without the activation (17). The results were even more efficient when the intracanal heating of NaOCL was done (18-20). However, heated NaOCL at 37 °C might be efficient in removing smear layer and debris without causing negative effects on the periapical surrounding tissues.
In the present study the volume, concentration, and irrigation protocol were similar in all groups except for the final activation system; moreover, a single operator performed the entire protocol to avoid any procedure or operator-related bias. However, some limitations should be stressed as the inclusion of single-rooted teeth. The real benefit of these devices would have better been evaluated when the curved and multirooted teeth were considered. Furthermore, shaping the teeth to size 40 would have caused a better smear layer removal not fully assessing the real-time benefit of using an activation system. Therefore, future studies should be better focused on these limitations and evaluate the device efficacy in minimal shapes and contracted access designs (21).

Conclusion

Within the limitation of the present ex-vivo study, it can be concluded that both Ultra-X and XPEF were equally effective in smear layer and debris removal in single-rooted mandibular second premolars.

Clinical Relevance

Clinicians currently have various rotary file systems and irrigant activation devices to choose for a routine endodontic practice. However, none of the available to date has proven to be efficient in completely removing the smear layer and the debris. The recently introduced XPEF has 3-dimensional canal wall contacts with better smear removal. Hence, in the present study we compared its debris and smear removal efficacy with the Ultra-X. Our results showed similar efficacy on using both the systems. The present study is clinically relevant as it compared a newer 3-dimensional file system with a popular and widely followed passive ultrasonic irrigation system.

Conflict of Interest

None.

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None.

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CASE REPORT

Intentional replantation for the management of an external cervical root resorption: a case report

Paolo Bertoletti*
Riccardo Tonini
Jacopo Francinelli
Stefano Gaffuri
Matteo Salvadori
Stefano Salgarello

[1]Department of Medical and Surgery Specialties, Radiological Sciences and Public Health, Dental School, University of Brescia, Italy

ABSTRACT

Aim: *To present the operative procedures carried out to manage a case of external cervical root resorption with pulp tissue involvement via endodontic treatment and intentional replantation, and the related clinical results obtained up to an 18-months follow-up.*
Summary: *After accurate clinical and radiographic evaluations, a diagnosis of external cervical root resorption has been established for the second maxillary right molar of a 27-year-old male patient. The patient referred chewing pain started about one year before. Through the signature of an informed consent, the patient has undergone root canal treatment of the element, followed by atraumatic extraction, resorption management and intentional replantation procedures. The tooth has been splinted for 14 days with the adjacent first molar, and after the healing period, it showed an adequate stability; moreover, no symptoms have been referred by the patient.*
The follow-up visits carried out after 3, 6, 12 and 18 months from clinical procedures confirmed the successful outcome of the treatment, as no recurrence, mobility or symptoms associated with the element have been currently reported.
Key learning points:
- *3D image acquisition represents an essential tool to diagnose external cervical resorptions and to accurately determine the position and the extension of the defect. Moreover, it allows a better operative planification which in turn is useful to define the most suitable approach for the single case.*
- *CBCT scan and the use of dental operating microscope considerably increase the accuracy of diagnostic, endodontic and conservative procedures.*
- *Intentional replantation should represent an effective therapeutic option for the management of deep external cervical root resorption.*

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KEYWORDS *External cervical resorption, intentional replantation, micro-endodontics, root resorption, three-dimensional diagnosis*

Corresponding Author
Paolo Bertoletti | Dental School, University of Brescia - Brescia (BS) | Italy
Tel. +39 030 3995 784 Email: paolobertoletti1993@gmail.com

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Introduction

External Cervical Resorption (ECR) is a dynamic resorptive process which starts from a cervical area and progresses in the coronal-apical direction, encircling the root canal. As a resorptive process, it is substantially characterized by an abnormal odontoclastic action resulting in the loss of dental hard tissues (1), mainly subepithelial cement. As extensively described by Mavridou et al. (2, 3), damages to periodontal ligament and the contribution of a stimulating factor to maintain osteoclasts activity may play a crucial role in the occurrence of ECR. Basing on existing literature, one single tooth is generally involved in ECR, although different cases of multiple cervical resorptions have been recently reported, in which more than one element was involved (4-6).
Different potential aetiological factors have been proposed over the years; nevertheless, the lack of evidence-based supportive literature resulted in a high percentage of missed diagnosis or inadequate defect treatment. The first cross-sectional study about the potential predisposing factors has been carried out in 1999 by Heithersay et al. (7). More recently, the relevant literature has been revised to better define the aetiological and pathogenetical aspects for ECR (8). It was found that, in the European population, orthodontic treatment and previous traumatic injuries are the major potential predisposing factors of ECR, followed by parafunctional habits, poor oral health, malocclusion, extraction of an adjacent tooth and - interestingly - viral infections related to the transmission of feline herpes virus (FHV) - although further investigations are necessary to well define that last correlation (2). Otherwise, a study by Jeng et al. (9) indicates trauma and periodontal treatment as major potential predisposing factors for ECR occurrence in Asian population. Concerning maxillary and mandibular second molars, different studies based on CBCT evaluations also found a correlation between external root resorption and impacted third molars, especially in those cases of mesio-angular impactions (10, 11). Nevertheless, no cause-effect relationship has been currently established, as it is still challenging to determine the exact nature of ECR defects when a combination of different predisposing factors in a single case is referred (12).
In the early stages of ECR, patients are commonly asymptomatic as the pulp tissue is vital and protected from resorption by the pericanalar resorption-resistant sheet (PRRS); on the contrary, in more advanced stages the resorption front may involve the pulp tissue, thus resulting in clinical signs and/or symptoms of pulpitis or apical periodontitis (1). For that reason, the clinical diagnosis is still unpredictable, and ECR defects are most frequently diagnosed as an incidental radiographic finding.
Before the clinical introduction of Cone Beam Computed Tomography (CBCT), periapical radiographs were the only radiographic support achievable to make ECR diagnosis. Nowadays, it is known that periapical radiographs present limitations due to image distortion (13), anatomical noise (14) and the impossibility to precisely evaluate the depth and the circumferential spread of the resorption (15); therefore, it may result in a misdiagnosis and a poor/no treatment of the defect. Due to the possibility to perform accurate three-dimensional analysis on dynamic images, and to adapt field of view and exposition to the region of interest, CBCT become almost essential over the years when diagnosis and treatment planification of complex endodontic treatments are required (16, 17).
Regarding ECR, the 2014 European Society of Endodontology (ESE) position statement and the 2015 joint statement of American Association of Endodontists (AAE) & American Academy of Oral and Maxillofacial Radiology (AAOMR) indicate CBCT as an effective tool to improve diagnosis quality and treatment planification of potentially restorable resorptions (18, 19).
The increasing need to better define the three-dimensional features of ECR in order to help clinicians to formulate an adequate treatment plan, recently lead to the development of three-dimensional classifications basing on CBCT findings on coronal, sagittal and axial views; in particular, Patel et al. (15) considered the coronal-apical ex-

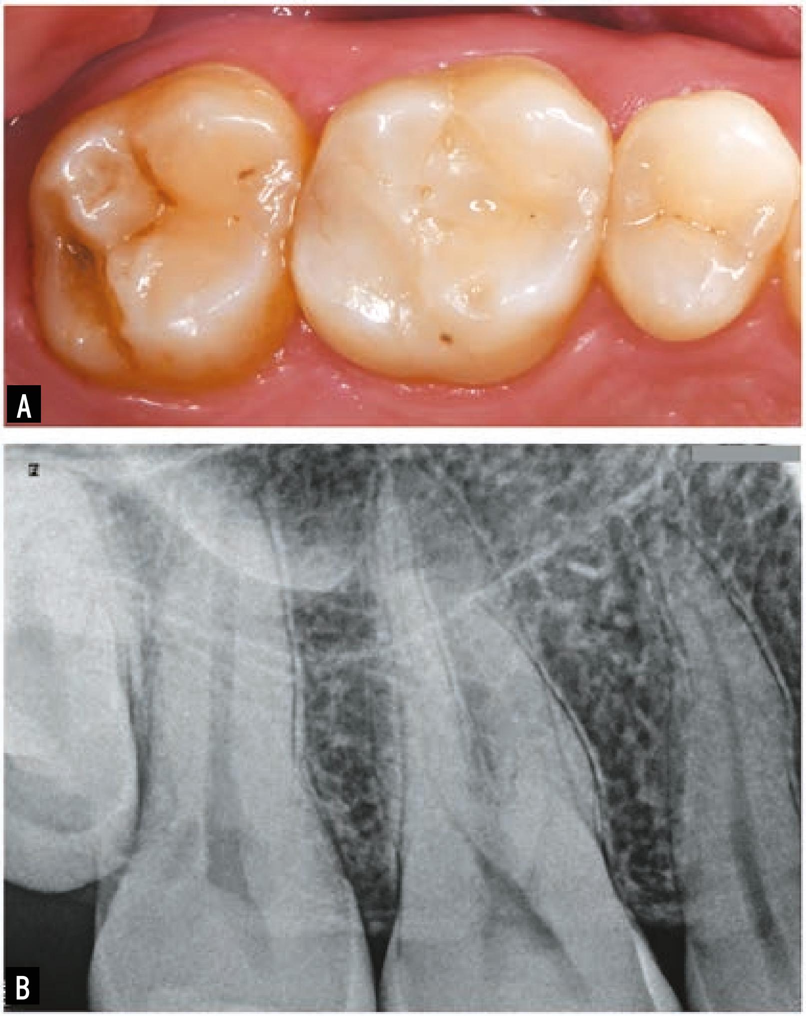

Figure 1
Clinical and radiographic situation at baseline: **A)** Occlusal view of teeth 1.5, 1.6 and 1.7; **B)** Periapical radiograph shows a radiotransparent area located on the distal side of element 1.7, with margins close to the pulp tissue.

tension, the proximity to the root canal and the circumferential spread of defects to improve diagnostic accuracy and to define the best treatment option, while Rhode's classification considers the amount of dentinal tissue loss both in cervical area and on the external surface of the tooth (20).
As previously mentioned, a scrupulous diagnosis is mandatory to define an adequate operative protocol for the management of each single case. The main objectives of ECR treatment are the excavation of the resorptive tissue and the restoration of the defect by using biocompatible materials (21). Tooth restorability and the accessibility and severity of the defect are among the main factors which direct the therapeutic choice.
Different approaches have been reported in literature regarding the management of ECR (22, 23); the necessity to perform endodontic treatment as part of the resorption management procedures is established on the presence or absence of referred symptoms due to the involvement of pulp tissue in ECR defect. In those cases of non-clinically accessible lesions, intentional replantation represents a valid therapeutic approach. It was originally described as the deliberate extraction of a tooth, followed by root surface evaluation, endodontic treatment and the reposition of the tooth in its socket (24). The technique is mainly indicated for single-rooted teeth, as the anatomical root conformation is more favourable for avulsion than that of multi-rooted teeth, thus resulting in easier procedure and minor damages to the root surface or risk of vertical fractures (23). The advantage of the procedure is that the entire coronal and radicular surfaces can be directly inspected and manipulated even in those areas where a conventional clinical approach is not achievable. The utmost attention must be paid during avulsion procedure to avoid mechanical damages to both periodontal ligament (PDL) cells and root surface. For that purpose, the use of elevators is not strictly recommended - or otherwise limited to gentle pressure gestures. To avoid excessive damage to gingival fibers during avulsion, it is suggested to place a sterile gauze on the tooth under the beaks of the forceps (25). It is essential that the debridement of the defect is performed with the aid of a dental operating microscope (22), to both ensure more precision and a conservative approach; the meticulous removal of the entire resorptive tissue is essential to reduce the risk of recurrence.
In literature, favourable long-term outcomes are associated with the procedure (26,27), demonstrating that intentional replantation should be considered as a valid and cost-effective treatment when the conventional clinical approaches are not feasible (28).
Basing on these favorable findings, the aim of the authors is to present the report of the multidisciplinary endodontic-surgical approach carried out to manage an extensive ECR in an upper right second molar with aberrant anatomy.

Figure 2
Cone Beam Computed Tomography has been performed to accurately define both location and extension of the defect: **A)** Sagittal view confirms the presence of an extensive resorption area on the distal side of tooth 1.7; **B)** Axial view indicates the close relationship between the pulp tissue and the resorption area.

Report

A Caucasian 27-year-old male patient referred to our private practice (Brescia, Lombardy, Italy) complaining occasional chewing pain started about one year before. The patient referred the symptoms in the molar region of the upper right maxilla, but he was not able to exactly indicate the tooth involved. The patient's medical and dental history were not relevant. Nevertheless, at the clinical interview the patient referred a severe motorcycle accident approximately ten years before, in which reported the fracture of the right cheekbone, fixed surgically. A visible scar was detected on the soft tissues in correspondence of tooth 1.7.
At clinical evaluation, both teeth 1.5 and 1.6 normally responded to vertical percussion and thermal pulp tests; on the contrary, tooth number 1.7 resulted to be positive for vertical percussion test. Periapical radiograph showed a suspect radiotransparent area located on the distal side of element 1.7, with margins closely adjacent to the pulp chamber (Figure 1).
To accurately define the nature of the symptoms and to determine a specific diagnosis, CBCT scan (CS 8100, CareStream, Rochester, New York) has been performed through the signature of an informed consent. On both sagittal and horizontal planes, an extended resorption area was detected, and pulp tissue involvement was evidenced. The CBCT sections in which the mentioned findings are appreciable are reported in Figure 2.
Basing on symptoms, clinical inspection and x-ray analysis, it was established a diagnosis of external cervical root resorption affecting tooth 1.7. The defect was classified as class 3Bp of Patel's three-dimensional classification for external cervical resorptions (15).
In the specific case, the patient has been advised about his treatment options, including the extraction of both elements 1.7 and 1.8 followed by the autotransplantation of 1.8 in post extractive 1.7 socket, or the intraoral root canal treatment (RCT) of element 1.7 followed by atraumatic extraction, extra-alveolar management of ECR defect, and intentional replantation.
The patient has been informed on risks and benefits of each option, and the two alternatives have been analyzed and discussed. After talks, he opted for the RCT and intentional replantation procedure. A written informed consent was read, accepted and signed by the patient prior to starting the clinical phase.
Both intraoral and extraoral procedures have been carried out with the aid of a dental operating microscope (DOM) (Leica M320, Leica Microsystems, Schweiz, Switzerland). As widely referred in Literature, the use of DOM allows dental practitioners to perform treatments in conditions of higher quality and under increased safety conditions (29).
Before starting the root canal treatment, the tooth 1.7 was anesthetized with 1.8 mL 4% articain containing 1: 100.000 adrenalin. The endodontic access was firstly obtained by using a small round diamond bur; then, a truncated-cone diamond bur has been employed to define the cavity. Ultrasonic Start-X tip 1 (Dentsply Maillefer, Ballaigues, Switzerland) has been used to refine the access. Once obtained a straight access to the endodontic system, a single, buccolingually extended, root canal orifice was detected, validating what observed in the pre-operative CBCT during treatment planification (Figure 3). At this moment, rubber dam isolation has been performed. Working length (WL) and apical patency were established using an electronic apex locator (Morita Denta Port ZX, Morita, Osaka, Japan). Root canal shaping was carried out by using Mtwo rotary nickel-titanium instruments (VDW, Munich, Germany) until the apical

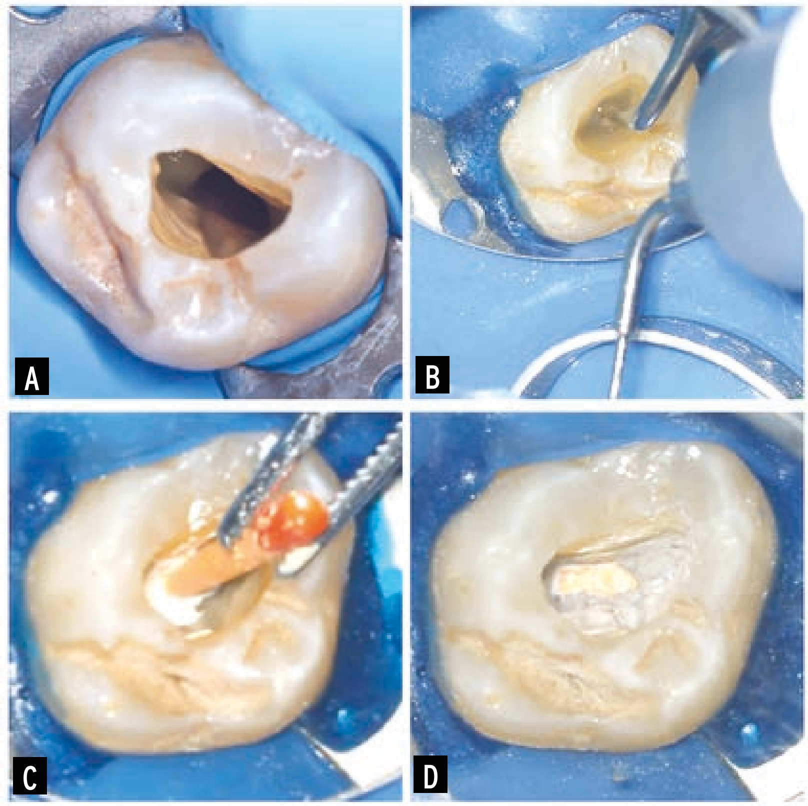

Figure 3
A) Access cavity and pulp chamber floor. The magnification obtained under dental operating microscope (Leica M320, Leica Microsystems, Schweiz, Switzerland) clearly shows a single, buccolingually extended, root canal orifice. **B)** Irrigants have been always ultrasonically activated during endodontic therapy by using a dedicated activator (Endo Cleaner, Dentalica, Milan, Italy). **C)** Root canal obturation has been performed by using a single gutta-percha cone and a bioceramic sealer (EndoSequence BC Sealer, Brasseler, Savannah, USA). **D)** Pulp chamber after obturation and debris removal.

size of 60/.04. Between the use of a rotary instrument and the successive, the root canal has been irrigated with 5.25% sodium hypochlorite (NaClO) by using a polymeric needle (IrriFlex®, Produits Dentaires SA, Vevey, Switzerland) coupled to a 5 ml syringe. Gentle up and down movements have been made during this phase, inserting the needle until a maximum distance of 2 mm from WL, and extruding NaClO drop by drop. Once established the definitive apical size, passive ultrasonic irrigation was performed with the aid of an ultrasonic activator (Endo Cleaner, Dentalica, Milan, Italy), alternating 5.25% NaClO and 17% ethylenediaminetetraacetic acid (EDTA) solution. In particular, both the irrigants have been extruded for one minute and then ultrasonically activated for 30 seconds. Then, the root canal has been rinsed with 5 ml of sterile saline and then dried with the aid of sterile paper points, remaining a little moisture to promote the properties of the calcium-silicate based sealer. The obturation was carried out by using a single gutta-percha cone in addition to bioceramic sealer (EndoSequence BC Sealer, Brasseler, Savannah, USA) (Figure 3). Once debris were removed from cavity, the tooth has been restored by light-curing composite resin (Filtek Supreme XTE, 3M ESPE, St. Paul, MN, USA).
The surgical phase of the treatment was entirely performed by using forceps, engaging the tooth exclusively on the crown and giving attention to perform the extraction as atraumatic as possible to both preserve alveolar bone integrity and reduce PDL cells trauma. After being extracted, the tooth was handheld by the crown by sterile gauze and sterile gloves, and the root was constantly irrigated with sterile saline to preserve surface hydration.
The extra-alveolar therapy has been entirely carried out with the aid of the DOM, and mainly consisted in the detersion of the resorption area and its restoration. The first phase has been performed by using a little round diamond bur until surrounding healthy tissue was reached; in the second phase, the resorption was filled with a

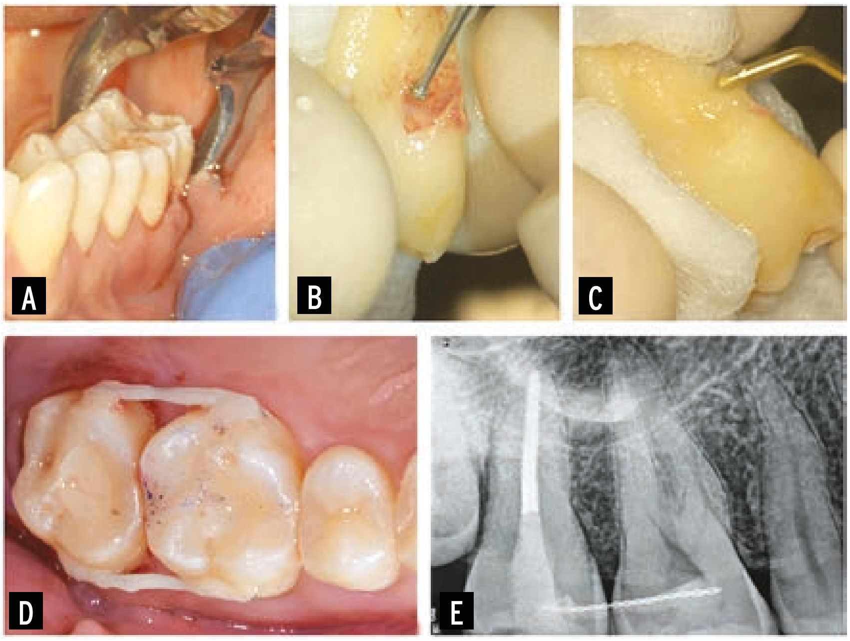

Figure 4
A) The avulsion of tooth 1.7 has been entirely performed by forceps and gentle, atraumatic movements. **B)** The tooth was handheld by sterile gloves and sterile gauze and constantly irrigated with sterile saline. The resorptive tissue has been removed by a small, round diamond bur under dental operating microscope (DOM) magnification. **C)** The defect has been restored under DOM magnification by using a self-etching and self-adhesive hybrid composite material (Surefil one, Dentsply Sirona, Charlotte, NC, USA). **D)** Intraoral photo taken after reimplantation shows teeth 1.6 and 1.7 splinted together by a double, resin-coated metallic splint. **E)** Post-operative periapical radiograph shows the excellent fit of element 1.7 in its alveolus after reimplantation, and the adequate restoration of the resorptive defect.

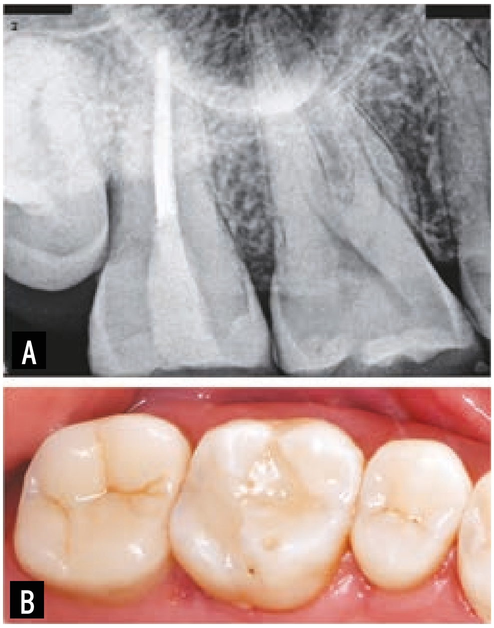

Figure 5
A) The periapical radiograph taken 3 months after does not reveal any complication during the healing process; **B)** Basing on the favourable outcomes, the tooth 1.7 has been restored through a conservative composite overlay to re-establish an adequate masticatory function.

light-curing, self-etching and self-adhesive hybrid composite material (Surefil one, Dentsply Sirona, Charlotte, NC, USA). The whole extraoral procedures lasted less than 15 minutes, as strongly recommended in Literature (23, 30). The quality of the apical sealing obtained by the previous RCT has been directly evaluated by DOM and was considered to be adequate.
To prevent the contamination of the site during the extra-alveolar procedures, blood-filled post-extractive socket has been preserved placing a sterile gauze.
The tooth was then re-implanted into the socket with forceps and properly repositioned by finger pressure, exerted both on the occlusal surface and then to the buccal and lingual bone plates together. To ensure stability, the elements 1.6 and 1.7 were splinted both buccally and palatally with a resin-coated metallic splint. Tooth 1.7 was then removed from occlusion to prevent occlusal forces to stress the element during the healing phase. Splint has been removed 14 days after the treatment, as recommended in the 2020 International Association of Dental Traumatology (IADT) guidelines for replanted teeth (31). Soft and hard tissues were correctly healing, and the patient referred a total absence of symptoms (Figure 4).
During the 3-months-recall, a periapical radiograph has been taken, and a clinical evaluation has been carried out. No symptoms have been referred from the patient, and no clinical signs of recurrence were detected. Tooth mobility, percussion sounds, and periodontal probing depth were all within normal ranges. In accordance with the patient, to re-establish an adequate masticatory function, the element has been coronally restored through a conservative composite overlay (Figure 5).

Figure 6
Follow-up visits confirm the successful outcomes of the treatment up to 18 months, as no symptoms have been referred and no clinical/radiographic signs of recurrence or ankylosis have been found: **A)** 6 months, **B)** 12 months, **C)** 18 months.

In Figure 6 are reported the periapical radiographs acquired respectively at 6, 12 and 18 months from clinical procedures. No signs of periapical lesion are detectable, and a good periodontal condition has been clinically observed. Tooth 1.7 was not tender to palpation or percussion, and no associated symptoms were referred. Furthermore, no metallic percussion sound – frequently indicative of ankylosis - has been recorded.

Discussion

The present case report describes the clinical approach carried out to save a maxillary right second molar affected by ECR, and the relative 18-months follow-up outcomes.
Maxillary second molars, as reported in Patel et al. (8), present a low percentage of appearance of ECR, especially if compared with other teeth as maxillary central incisor or maxillary canine. In the present report, ECR diagnosis was established for the maxillary right second molar; interestingly, the element showed an aberrant root and endodontic anatomy, as one single root and one single root canal have been detected. Single-root and single-canal maxillary second molars are quite rare; the most recent CBCT studies available in literature about the incidence of such aberrant root and endodontic anatomy have been mainly conducted on different Asian populations, providing heterogeneous outcomes (32-34). No studies about the incidence of that aberrant anatomy in the European population has been currently detected in literature.
In those cases of aberrant anatomy, iatrogenic errors when searching for missing canals should be avoided by a meticulous diagnosis and with the support of pre-operative CBCT and the use of DOM during RCT (35).
As reported in the previous section, the tooth was involved ten years before in a severe motorcycle accident, in which the patient reported right cheekbone fracture. As traumatic episodes are referred in Literature as major predisposing factors for ECR appearance (36), a possible cause-effect relationship should not be excluded in the present clinical case. In addition, considering the results of a recent meta-analysis in which emerged the influence of impacted third molars as a strong risk factor for second molars external root resorption (37), and the anatomical relationship existing in the present report between teeth 1.7 and 1.8, a possible correlation cannot be ignored. The complexity in determining the exact cause of the resorption confirms its multifactorial nature and thus the necessity to further investigate about the aetiological and pathogenic aspects underlying ECR.
Different therapeutic options such as defect restoration - when clinically accessible-, surgical extrusion, intentional replantation or autotransplantation are available for the treatment of ECR defects. Among them, intentional replantation is one of the last treatment options to save teeth involved in ECR. Torabinejad et al. found a mean survival rate close to 90% for root canal-treated and intentionally replanted teeth, with a mean prevalence of resorption lower than 11% (38). Further, although the different radicular and endodontic anatomy, a recent systematic review reported a survival rate of 88.64% for reimplanted single-rooted teeth, and of 85.57% for pluriradicular teeth; the reported overall survival rate for inten-

tional replantation procedure is around 86,7%. No statistically significant differences have been reported from authors in terms of survival rates between single- and multi-rooted teeth (39). Concerning endodontically treated teeth with existing periapical pathosis, the mean survival rate recently reported by Javed et al. is around 85.9% (40); the authors also reported that factors such as an extra-alveolar therapy time shorter than 15 minutes, manipulation of the element exclusively by the crown and appropriate storage media seems to crucially influence the successful outcome of the therapy. The avulsion is probably the most crucial phase of the entire therapy, as gentle and fine movements are essential to both reduce damages to PDL cells and to prevent the risk of root fracture, which is reported as one of the major risk factors for that approach, especially when in presence of an extended resorption area (41).

When a tooth affected by ECR appears to be restorable following clinical and conventional radiographic examination, CBCT scan represents an essential supportive tool. Different studies have proven the superiority of CBCT rather than periapical radiographs in providing accurate information regarding size, location and circumferential spread of defects (13, 21). Moreover, CBCT imaging allows to better identify even the incipient lesions if compared to periapical radiographs (42), other than missed canals, vertical root fractures and complex anatomy (43). Concerning root resorptions, Dao et al. (44) recently found a high rate of incidental findings of resorption areas detected by CBCT scan of patients referred for a variety of indications, suggesting that conventional radiography is not equally effective and therefore the defect is often underdiagnosed. As mentioned, it is essential that CBCT exams are justified over conventional techniques prior to being performed; ALADA principle must be applied (45), and the benefits of the three-dimensional examination must always overweight the risks (46).

Different materials such as glass-ionomer cements, fast-setting calcium silicate materials and composite resin have been proposed for the restoration of the resorption area; their application mainly depends on extension, morphology and location of the defect (18). As indicated by Plotino et al. (23), when composite resin is chosen, it is crucial to prevent damages to PDL cells, thus avoiding that both etchant gel and adhesive come in contact with the root surface, other than the risk of heat-induced damages during composite polymerization.

Basing on the previous considerations, in the present clinical case the entire treatment has been carried out under DOM magnification, to both ensure more precision during RCT and resorption management, and a greater visibility of the area to the operator. Patel et al. (22) reported that magnification and illumination are essential requirements to correctly distinguish between sound dentin and fibro-osseous deposit tissue.

As recommended in literature, a reduced extra-alveolar time is crucial for the positive outcome of the treatment (27, 30, 40). In the present case report, as clinical conditions were favourable due to the aberrant endodontic anatomy, the extra-alveolar time has been reduced performing the endodontic treatment intraorally, relying on the extraoral phase the only management and reconstruction of the defect. Moreover, to prevent the forementioned risk due to the use of both etchant and adhesive, a self-etching and self-adhesive hybrid composite resin has been employed for the restoration of the resorption, providing all the benefits of a reduced number of steps and a decreased probability of PDL damages.

Clinical signs of ankylosis such as metallic percussion sounds are generally detectable within 4-8 weeks after clinical intervention, although late complications should not be excluded (27). Currently, none of those signs has been detected in the present 18-months follow-up, supporting the favourable outcome of the treatment.

Conclusions

As the clinical diagnosis is still unpredictable, ECR represents a clinical challenge in modern Endodontics. Moreover, when resorption fronts develop in non-clinically accessible areas, the increased complexity

of the treatment requires operative strategies different from the conventional clinical approaches. Among them, intentional replantation is well supported by literature and clinical results, and thus should be considered as an affordable treatment option for the management of deep root resorptive defects, and not merely an unpredictable approach for hopeless teeth. The objective of intentional replantation is the preservation of the dental element, avoiding – or reasonably delaying - the insertion of a dental titanium implant. As widely stressed, CBCT scan and dental operating microscope represents crucial tools to achieve respectively a specific and detailed diagnosis and a high quality of the treatment.
Basing on the mentioned favourable findings, the current observation period is considered by the authors to be long enough to indicate the successful outcomes of the multidisciplinary approach proposed in the present case report.

Clinical Relevance

Clinical and radiographic results obtained up to an 18-months follow-up indicates the proposed multidisciplinary approach as a viable treatment option to manage complex cases of non-clinically accessible ECR, thus allowing the preservation of the involved tooth in the oral cavity.

Conflict of Interest

The authors declare that no conflict of interest exist.

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REVIEW ARTICLE

Diversity of root canal morphology in mandibular premolars and its treatment strategies

ABSTRACT

Variations in root and canal configurations can be observed in every tooth group. Mandibular premolars are a group of teeth where deviations in the root canal anatomy are common and are among the most difficult to treat endodontically. Diagnosis of root canal anomalies before endodontic treatment is a basic requirement. The root number and canal configurations aberrations such as double canal, C-shaped root canal system, 3-, 4-, and 5-canal are observed in mandibular premolars. There are relationships between some coronal and radicular features and multiple canal anatomy in mandibular premolars. There are significant correlations between external root morphologies and internal root canal systems of the mandibular premolars. Similarly, root characteristics may be related to some coronal features. This comprehensive review aims to examine the morphological variations observed in mandibular premolars and discuss the clinical and radiographic signs in the diagnosis of teeth with complex root canal systems before endodontic treatments.

Hakan Aydın[1]

Kürşat Er[2*]

[1]Department of Endodontics, Faculty of Dentistry, Antalya Bilim University, Antalya, Turkey.

[2]Department of Endodontics, Faculty of Dentistry, Akdeniz University, Antalya, Turkey.

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Corresponding Author

Prof. Dr. Kürşat Er | Department of Endodontics, Faculty of Dentistry, Akdeniz University, Antalya | Turkiye.

Tel. +90 (505) 6542725, fax: +90 (242) 3106967 | Email. qursater@hotmail.com

Email: raghupublications820@gmail.com | Tel: +601128001325

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Introduction

Observing variations in root canal morphologies is a common phenomenon for all tooth groups, and after numerous studies (1-3) and case reports on this subject, this situation is now considered routine. Root canal treatment (RCT) success can be achieved by managing accurately all treatment stages. The basic prerequisite for achieving this is a comprehensive knowledge of the anatomy of the root canal complexity (2). The anomalous root canal morphology can be observed in every tooth group with different percentage and degree, and when ignored, it is 1 of the major causes of endodontic failure (3,4). Having information about all root canal combinations that may be encountered and considering the possible existence of additional root canals and complex root canal systems in each case before endodontic procedures will minimize undesirable treatment results (5).

Mandibular premolars are 1 of the tooth groups with complex canal shapes and are thought to be the most difficult to treat (1). There may be a misperception that their treatment is easy because they mostly exhibit a single root/root canal character and contain an oval form in cross-section and an oval root canal compatible with this form. However, these teeth are 1 of the tooth groups that show wide morphological variation. Second canal frequencies are significantly higher (6). Besides the double canal variant, the numbers and root canal configurations aberrations with C-shaped root canal system (7), 3-canal (8,9), 4-canal (2), and 5-canal (10,11) have been reported in the literature on mandibular premolars. Due to such a wide spectrum of canal variability, it is defined as the *Endodontist's Enigma* (12).

One of the basic prerequisites in the ideal treatment of mandibular premolars exhibiting anomalies in the root canal morphology is to diagnose this condition before treatment. Therefore, the aim of this review study was to examine the clinical and radiographic features that should be taken into consideration in the diagnosis of root canal configurations observed in mandibular premolars. This is thought to help clinicians in the treatment process.

Review

Prevalence of multiple canals

There are many epidemiological studies (13-15) conducted on mandibular premolars in different populations, races, ethnicities, and geographical regions, and the dominant root canal anatomy in both mandibular premolars is that they are 1-root and 1-canal. In a systematic review (16) that included studies in which all methodologies evaluating root canal anatomy were used as analytical tools, a prevalence of 97.2% 1-root and 2.6% 2-root were reported in first premolars. On the other hand, the presence of a 1-canal was found to be 73.55%, while the prevalence of a second canal was detected at a high frequency of 23.55%. Complicated root and canal structure was less detected in mandibular second premolars, and a 1-root prevalence of 99.28% and a 1-canal prevalence of 86.9% were presented (16). In a recent review that compiled studies using cone-beam computed tomography (CBCT) and micro-CT imaging as evaluation methods, the presence of multiple canals was found in 26.7% of mandibular first premolars and 8.2% of second premolars (17). Another recent systematic review (18) on mandibular second premolars reported that studies presented a complex canal prevalence of 0-10.5%. In these mentioned reviews, 3 and/or more root canals were rare in both premolars.

Especially with the increasing use of CBCT for dental purposes, the number of studies (1,6,19) on the prevalence of root and canal anatomy has increased in the last decade. In this way, the disadvantages of performing *ex vivo* studies on a limited number of teeth have been overcome (20). With larger sample numbers, the actual incidence rates in the researched population are better understood (21). The unclear interpretation of 2D radiographs has been resolved, and the effects of demographic and individual factors such as sex, tooth position, age, and symmetrical involvement can be revealed (22). It is known that ethnic and geographical regional differences are effective factors in the root canal anatomy pattern in all tooth groups (3). In a CBCT study evaluating the prevalence of canal multiplicity in mandibular premolars from 23 different countries, the world average was found to be 23.8% in first premolars and 5.3% in second premolars (13). The lowest lingual canal prevalences were presented in Australia and East-Asian countries for both premolars, the highest in Africa for first premolars, and the highest in Europe, Africa, and West Asia geographical regions for second premolars. Complex root canal system in mandibular premolars is more common in men and shows sex differences (13,18).

The most common canal configuration in mandibular premolars with complex root canal anatomy is Vertucci type 5 (1-2, Fig. 1). Vertucci type 3 (1-2-1), type 2 (2-1, Fig. 2), and type 4 (2-2, Fig. 3) are other more common configurations (1, 6, 14).

Coronal and radicular features

There are significant correlations between external root morphologies and internal root canal systems of the teeth (5). Similarly, root characteristics may be related to some coronal features (21). Clinical and radiographic examinations of crown and root structures before RCT are the first steps in understanding complex root canal configurations. The mesiodistal (MD) and buccolingual (BL) dimensions of the crown, crown height, and distance between cusps are some macromorphological metric features that should be examined before RCT (23). In teeth with wider crown widths, the number of roots and canals and the possibility of exhibiting complex canal features may increase (21). Additionally, the increase in the number of cusps and/or their being more prominent may result in deviation from the normal root anatomy (21). As in the crown structure, the development of tooth roots or the presence of radicular structures such as developmental grooves can lead to complex root canal anatomy (24). For this reason, it is important to visually examine the coronal structures of the teeth and evaluate their metric and non-metric properties before the treatment.

Mandibular premolars have 2 tubercles, 1 on the buccal and 1 on the lingual (23). That's why another name for these teeth is lower bicuspid teeth. Turner et al. (25) determined all non-metric features that could be observed for all tooth groups in 1991, based on their observations, anthropological studies, and literature information over many years, and made a scoring system according to their existences and degrees. The graded standards of these dental characteristics called the Arizona State University Dental Anthropology System (ASUDAS), are widely used in dental anatomy (26-28). In this scoring system, non-metric dental features that may be specific to mandibular premolars are stated as follows; presence of odontoma on the occlusal surface, lingual cusp variations (absence of cusp in the lingual region, presence of 1-, 2-, or 3-cusp in the lingual and size differences of buccal/lingual cusp), presence of developmental radicular grooves, Tomes' root, and number of roots. Identifying these features(s) and

Figure 1
The most common second canal type in mandibular premolars is Vertucci type 5 (1-2). Root canal system, which continues as a 1-canal after the CEJ, ends as 2 separate canals separating in the coronal, middle, or apical thirds.

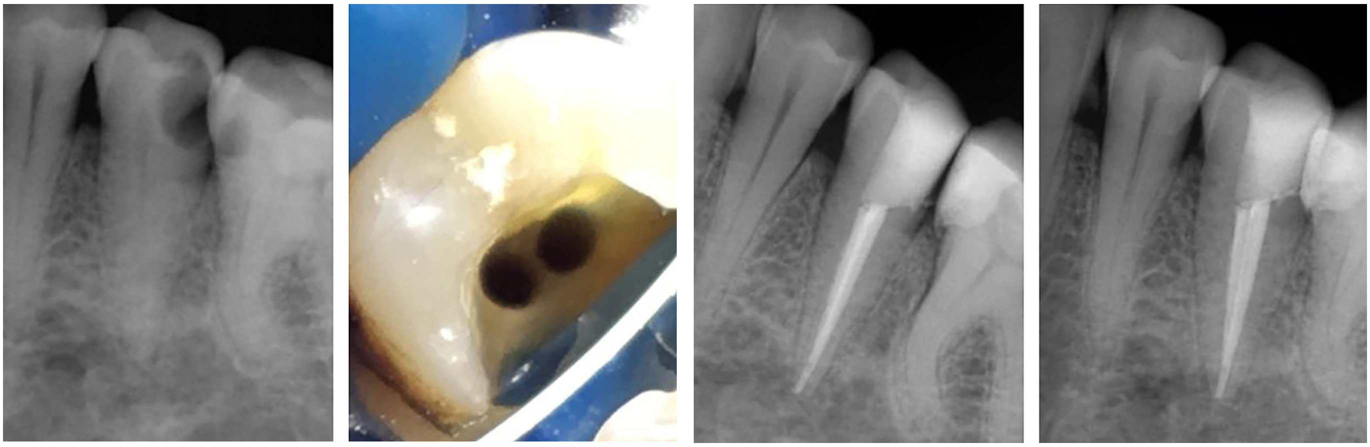


Figure 2
RCT of a mandibular second premolar exhibiting Vertucci type 2 (2-1) root canal configuration. A 1-canal is observed in the pre-operative periapical radiography. However, the eccentric location of the canal in the root indicates the presence of a second canal.

having knowledge about their effects on root canal diversity can be useful in diagnosing.
Among the mentioned non-metric characteristics, the most important features that cause complexity in root canal anatomy are the presence of developmental grooves and Tomes' roots.

Developmental radicular grooves and Tomes' root trait
Root grooves are longitudinal depressions located on the root surfaces of teeth (27). Advantageously, these grooves increase the area of the root surface and load capacity of the periodontal membrane. However, these depression areas are one of the predisposing factors for the onset and spreading of localized periodontitis. These grooves act as reservoirs for microorganisms and can lead to persistent infections (26).
In mandibular premolars, when the roots are divided into 2 or 3 by root furcation and terminate independently, they are considered separate roots. On the other hand, the presence of longitudinal developmental root grooves along the root and 2 or more unseparated root-like division cones in a 1-root are called radicals and are not designated as separate roots (25,29). There are 2 separate roots in maxillary

Figure 3
RCT of a mandibular second premolar with Vertucci type 4 (2-2) root canal configuration. The initial radiograph taken at a straight angle provided limited information about the second canal. The presence of the second canal is observed in the angled radiograph.

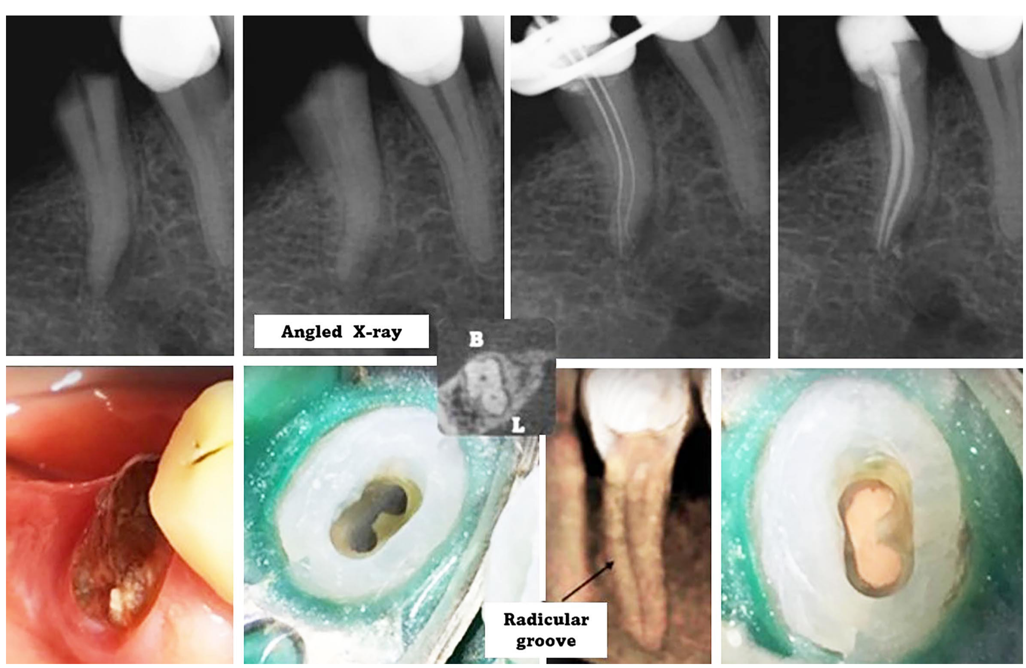


Figure 4 Examples of radicular grooves according to the ASUDAS scoring system.

premolars, or in cases where 2-root are fused, these roots are round in cross-section. However, in the presence of root grooves in mandibular premolars, the cross-section of the roots has a form that cannot be identified as separate roots. Radicular grooves in mandibular premolars were examined in detail anthropologically and a scoring system was developed according to their severity (Fig. 4) (29,30). According to the ASUDAS classification, the scores are as follows. **Score 0:** Developmental groove is absent or, if present, shallow rather than a V-shaped depression; **Score 1:** Developmental groove is present and has a shallow V-shaped cross-section; **Score 2:** Developmental groove is present and has a V-shaped cross-section of moderate depth; **Score 3:** A V-shaped and deep groove is present. The groove extends at least one-third of the entire length of the root; **Score 4:** Double groove present on both mesial and distal surfaces; **Score 5:** Two or more roots present. Teeth other than Score 5 are considered single-rooted. Cases Scores 3 and 4 (teeth with deep radicular grooves) are known as Tomes' root trait.

Radicular grooves in mandibular premolars may differ in terms of depth, length, complexity, and location (26). Grooves deeper than one-third of the root in the BL or MD direction are called deep grooves, and those that are more superficial are called shallow grooves (31). Not every indentation is described as a groove; if there is only a shallow and rounded indentation extending longitudinally on the proximal surface, it is called a concavity, and if there is a V-shaped cross-section, it is called a radicular groove (26). Radicular grooves, whose incidence is affected by differences in race, population, geographical region, and examination method, are encountered with a prevalence of up to 40% in mandibular first premolars (32). It is less common in mandibular second premolars (33). Developmental root grooves are often located on the mesial surface of the root, especially in the mesiolingual (ML) region (7,32). However, it can also be seen on the distal, buccal, and lingual surfaces of the root (6,26). These invaginations, located on the proximal surface, form a C-shaped root in cross-section of the root. It can be single or can be found on both sides of the root (26). The initial level is approximately 3 mm below the cemento-enamel junction (CEJ) (7). The deepest points are in the middle levels of the root (27). Not all radicular grooves continue apically. Most of them initiate in the coronal third and end in the apical third (32). The groove length is approximately 65% of the root length (7). Only 40-43% extends apically (7,32). As it is located mostly on the mesial surface of the root, it causes significant reductions in dentin thickness on this surface (34). Increasing groove depth and angle leads to significant decreases in mesial dentin thickness (34). In a study (34) evaluating C-shaped mandibular premolars with radicular grooves, it was shown that the mesial canal wall could decrease up to 0.17 mm.

The most important point from an endodontic perspective is that there is a serious relationship between the radicular groove and the complex canal forms (Fig. 5) (31). A broad spectrum of morphological deviation is observed in mandibular premolars with radicular grooves (26). In a micro-CT study (26), only 8.5% multiple canals were observed in mandibular first premolars without Tomes' root (ASUDAS 0-2), while this proportion was found to be very high as 78.2% in the Tomes' root group. Additionally, the incidence of multiple canals increased with a rising ASUDAS score. In another study, the presence of 2 or more canals was found in 93.8% of mandibular first premolars with radicular grooves (35). Many *ex vivo* and *in vivo* studies have supported this finding (6,27,32). More than half of the mandibular first premolars, which feature Tomes' root (ASUDAS 3-4), have double canals as well as 2 separate canal terminations, which further increases the importance of the treatment of these teeth (27). It has been shown that the radicular groove depths in teeth with 1-canal morphology are less shallow than in double canal variants and do not extend to the apex (32).

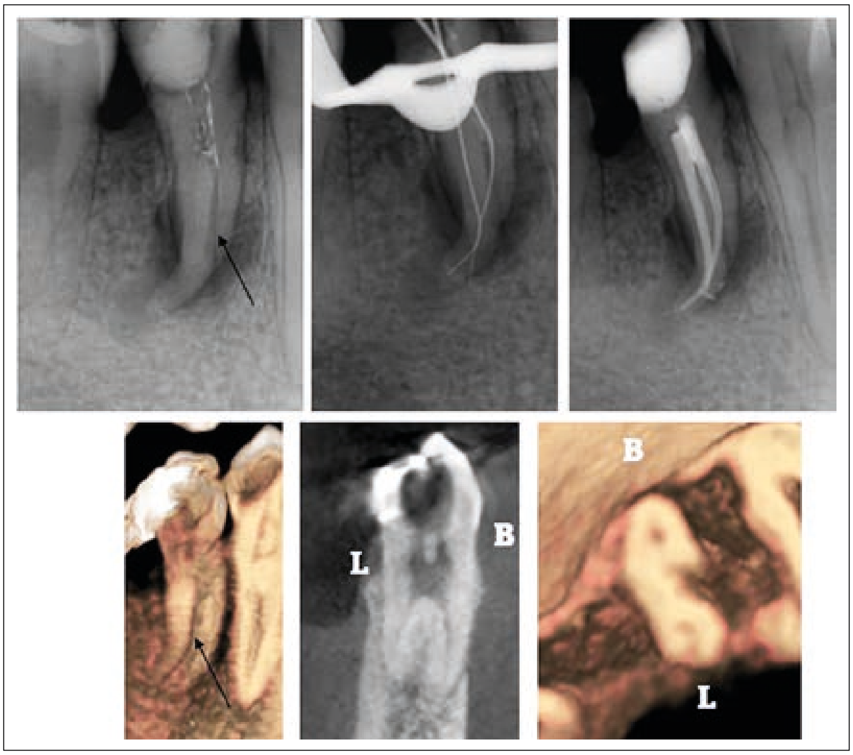


Figure 5
There is a significant correlation between the presence of a radicular groove and the presence of the second canal. Radiographic and CBCT views of the mandibular first premolar with a radicular groove on the mesial surface extending to the root apex. The radicular groove is observed as a distinct vertical line on the radiograph (black arrow).

Mandibular premolars with radicular grooves also have high furcation canal (33%) and apical delta frequencies (43%) (24). Furcation canals, called radicular groove accessory canals, originate from the pulp chamber or the semilunar buccal canal close to the canal furcation and end in the radicular groove (28). Diameters can be as large as 0.21 mm and may cause an extension of the endodontic lesion into the periodontal region (Fig. 6) (28). When primary endodontic infection causes a periodontal lesion, it may cause the formation of a deep pocket, raising suspicion of a vertical fracture.

Another common canal feature in teeth with radicular grooves that needs to be examined in detail is the C-shaped root canal system.

C-shaped root canal system

Although the C-shaped root and canal system is an anatomical formation that is mainly observed in mandibular second molars, it can also be observed in maxillary molars and mandibular premolars (1,36). The C-shaped feature, characterized by the presence of webs and fins between individual canals, has been a subject of particular interest as it poses many therapeutic challenges. There are fundamental differences between the C-shape root canal system in mandibular molars and premolars. While it is observed in mandibular molars when the mesial and distal roots are fused because of incomplete separation, in mandibular premolars it is observed in cases of radicular groove, which is an attempt to increase the number and complexity of the roots. C-shape structure in mandibular premolars is evaluated separately based on root and root canal (7,31). Single-rooted mandibular premolars, where a deep radicular groove is present, have a C-shaped root structure in cross-section (Fig. 5 and 6).

Different root canal shapes are observed in cross-sections of C-shaped mandibular premolars. Fan et al. (7) determined 6 different configurations could be observed in C-shaped mandibular premolars cross-sections. **Category 1 (C1):** Resembling the letter C, continuous shape without any

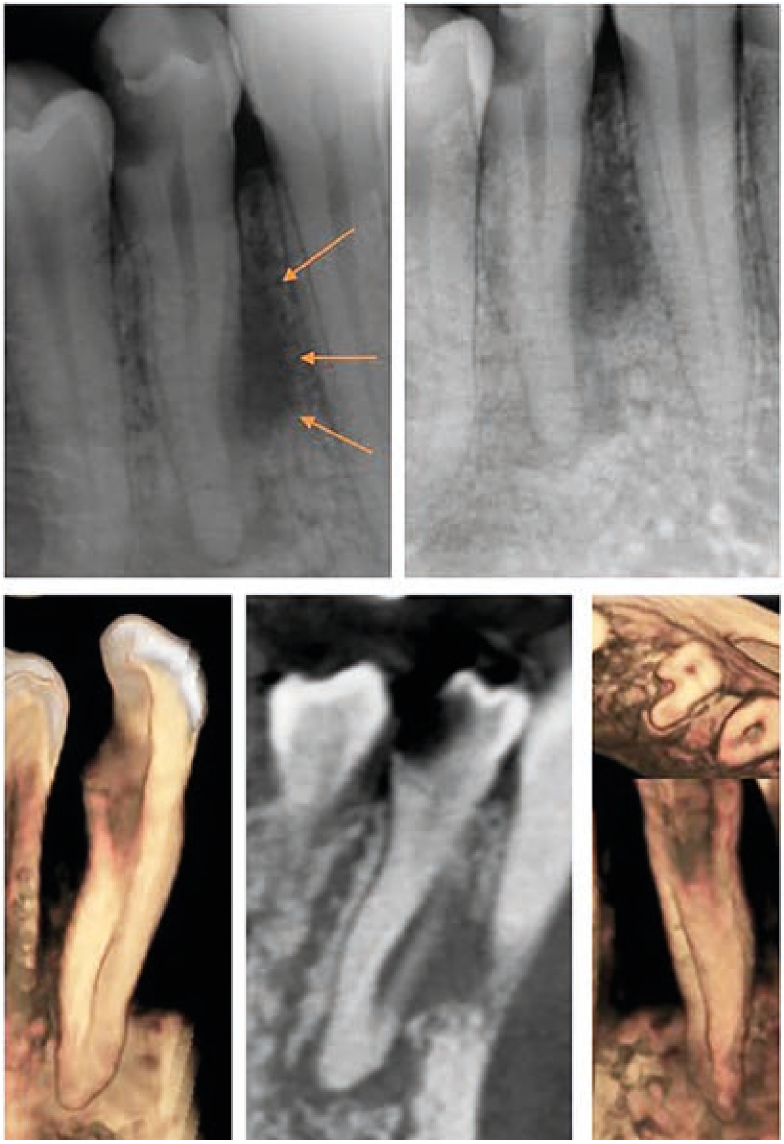


Figure 6
Periapical and CBCT images of the mandibular first premolar with apical periodontitis. There is a deep radicular groove on the ML surface of the tooth and a radicular groove extending to the apex (ASUDAS scoring class 3, Tomes' root, clearly visible on the angled periapical radiograph). There is a lateral lesion centered on the deepest level of the groove. The primary endodontic problem through the radicular groove accessory canal caused the periodontal lesion.

division or separation between the canals; **Category 2 (C2):** A semicolon-like shape, without continuity in the outline of the letter *'C'*; **Category 3 (C3):** With two flat, oval, or round canals; **Category 4 (C4):** A single canal is present; this category has 3 subtypes. *C4a*, round form with nearly equal aspect ratio of the canal. *C4b*, oval canal form in which the long diameter of the canal is less than 2 times the short diameter. *C4c*, flat canal form in which the long diameter in the cross-section of the canal is more than twice the short diameter; **Category 5 (C5):** With 3 or more canals; **Category 6 (C6):** Canal lumen not visible. Four different features can be seen in C-shaped mandibular premolars (31); *a)* Only continuous C-shape: this type has a continuous C-shaped canal system. This C-shaped canal gradually turns into a non-C-shaped round or oval canal or divides into 2-canal; *b)* Semilunar buccal canal; the single canal system, which starts as oval coronally, then divides into a semilunar buccal canal and a non-C-shaped lingual canal. The semilunar buccal canal may later turn into a smaller semilunar canal or a non-C-shaped canal; *c)* Combination of a continuous C-shape and a semilunar buccal canal: a continuous C-shaped canal is divided into a semilunar buccal canal and a non-C-shaped lingual canal; *d)* Semilunar buccal canal is interrupted by 1 or smaller non-C-shaped canal. A mandibular premolar tooth with a C-shaped root structure is not included in the C-shaped root canal system category if it has 2 separate, non-C-shaped root canals (34). In cases of *C1*, and *C2* configuration and the presence of a significant isthmus between 2/3 canals, it is considered a C-shaped tooth (26,34). In some CBCT studies, the conditions of the presence of radicular grooves and exhibiting *C1* and *C2* configuration at any position of the root canal system have been considered (33). Different diagnostic criteria and examination methods have led to variable prevalence being reported. As with radicular grooves, C-shaped root canal prevalence is affected by ethnic and regional differences and varies depending on the methodology used. A relatively high prevalence of 20% has been reported in *ex vivo* micro-CT studies (26,34). Conversely, lower incidences have been presented *in vivo* CBCT studies. Martins *et al.* (33) reported low prevalences of 2.3% for first premolars and 0.6% for second premolars in the Portuguese population. In another study, it was reported that in the Turkish population, it was 4.6% in first premolars and 1.1% in second premolars (6). Their incidence is higher in the first premolars (33). There have been reports that C-shape is more common in men (33). However, no difference was observed in terms of tooth position (33). It has been observed that it is more unilaterally (33).

There is mostly a 1-canal in the coronal third of mandibular premolars with a C-shaped root canal system (7). Since radicular grooves are mostly located in the middle third, the prevalence of *C1* and *C2* canal configurations increases in this region. *C2* and *C3* canal shapes are dominant in the apical third. (7). Because the C-shape configuration is located after the orifice of a round or oval canal and away from the apex, the root structure has been named by 3 different names. Non-C-shaped coronal and apical section and C-shaped middle section (31). C-shaped canals are mostly located 6-11 mm below the CEJ (34). There is a strong correlation between the presence of radicular grooves and the C-shape. In a study comparing mandibular first premolars with and without radicular grooves, no C-shape configuration was detected in any teeth without radicular grooves (31). On the contrary, C-shaped canals were identified in 66.2% of teeth with radicular grooves. Additionally, C-shape was observed to be more relevant in deep grooves. In another *ex vivo* study (24), 67% C-shape configuration was found in mandibular premolars with radicular grooves. In an *in vivo* study (6), all C-shaped canals encountered in both premolars were detected in teeth with radicular grooves.

The root length, which continues as a C-shape, is approximately 4.5 mm (31). Mandibular premolars with buccal radicular grooves are observed especially in the second premolars, and the axial morphology creates a *'reversed C-shaped canal system'* (15). In these cases, the main canal is almost close to the lingual surface of the root.

Since radicular grooves are so important in mandibular premolars, their presence should lead clinicians to be more careful about the second canal.

Mandibular premolars with 3-5 root canals

It is scarce variation for mandibular premolars to have 3 or more canals (1). Information about the external and internal root canal anatomy of teeth with 3-canal consists mostly of case reports (4,8,9,37). There is only 1 study (38) in the literature on the qualitative and quantitative characteristics of mandibular premolars with 3-canal. In this study, 16 mandibular premolars with 3-canal were evaluated. Nine of the 16 teeth were seen in single-rooted teeth with radicular grooves (Fig. 7 and 8). In 3 samples, although the main root was divided into mesial and distal by a deep groove at the middle level, it continued to be fused up to the apical. In 3 samples, it was determined that there was division at the apical level on the buccal side of the root. Only 1 sample was observed to have 3 separate roots (Fig. 9 and 10). That is, 3-canal teeth mostly have 1- or 2-root (Fig. 7 and 8). In 15 of these teeth, canal localizations were observed as mesiobuccal (MB), distobuccal (DB), and lingual canals (Fig. 7-10). In the other single tooth, 1 buccal and 2 lingual canals were observed. Cases of fusion of DB/Lingual and DB/MB canals have been detected. While the shape of the canal orifices was triangular except for 1 tooth, it was found to be linear in 1 tooth. In mandibular premolars with 3-canal, this location of the canals allows the de-

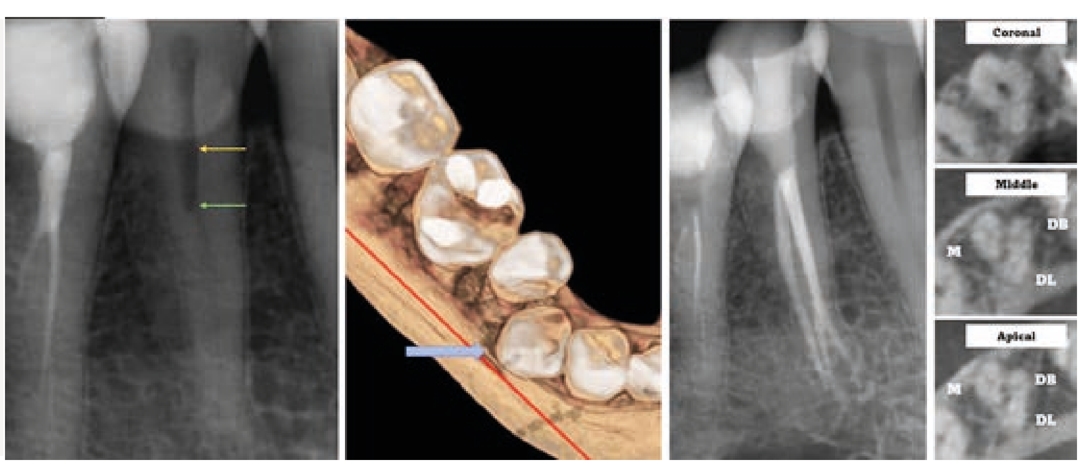


Figure 7
RCT of a mandibular first premolar with a 1-root and 3-canal. The root canal system begins as a 1 common canal (yellow arrow). The canals are divided into 3 by canal trifurcation, which is localized in the coronal third (green arrow). Root canals are in MB, DB, and DL.

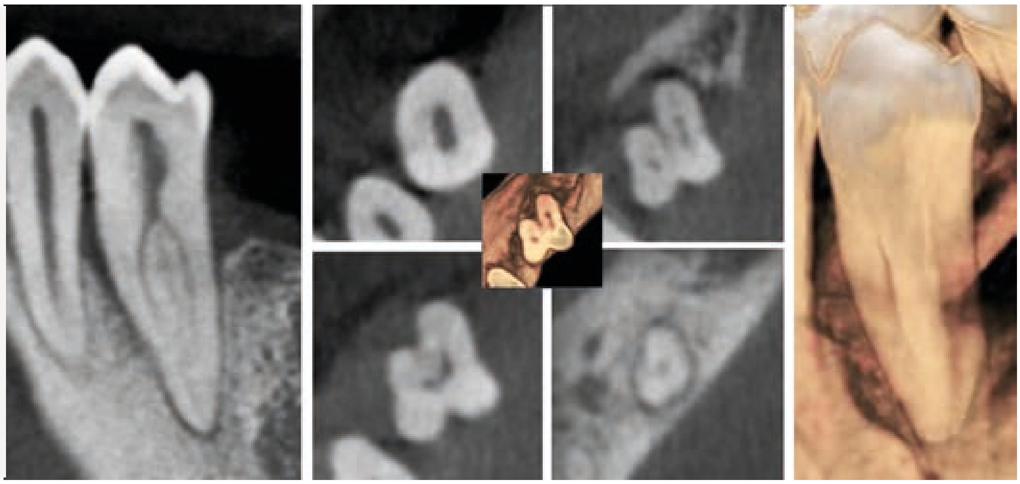


Figure 8
CBCT multiplanar and reconstruction images of a mandibular second premolar with a 1-root and exhibiting 1-3-1 root canal configuration. There are 2 radicular grooves on the buccal and lingual surfaces of the tooth (ASUDAS score 4, Tomes' root). Root canals begin as a single, oval, common canal, and the canal trifurcation point is in the coronal third. Root canals are MB, DB, and DL. While the DB and DL canal orifices are closer to each other, the distance between the MB and lingual canal orifices is the longest.

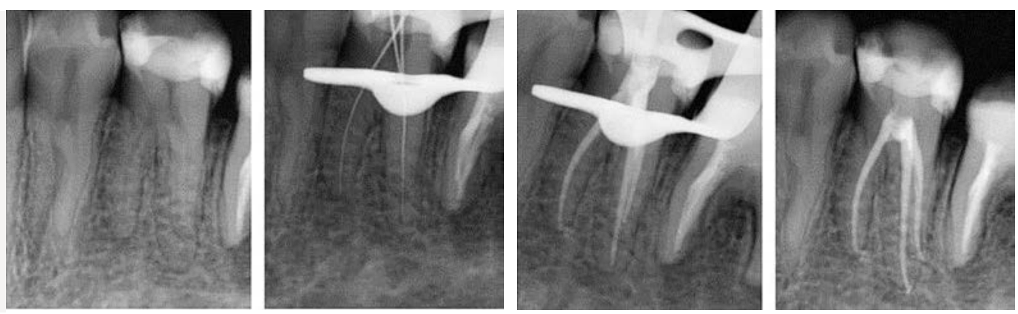


Figure 9
Initial, working length, main apical cone, and final periapical radiographs of the 3-rooted lower left mandibular second premolar (ASUDAS score 5). The periodontal ligament spaces of the 3-root are diagnosed on the pre-treatment periapical radiography.

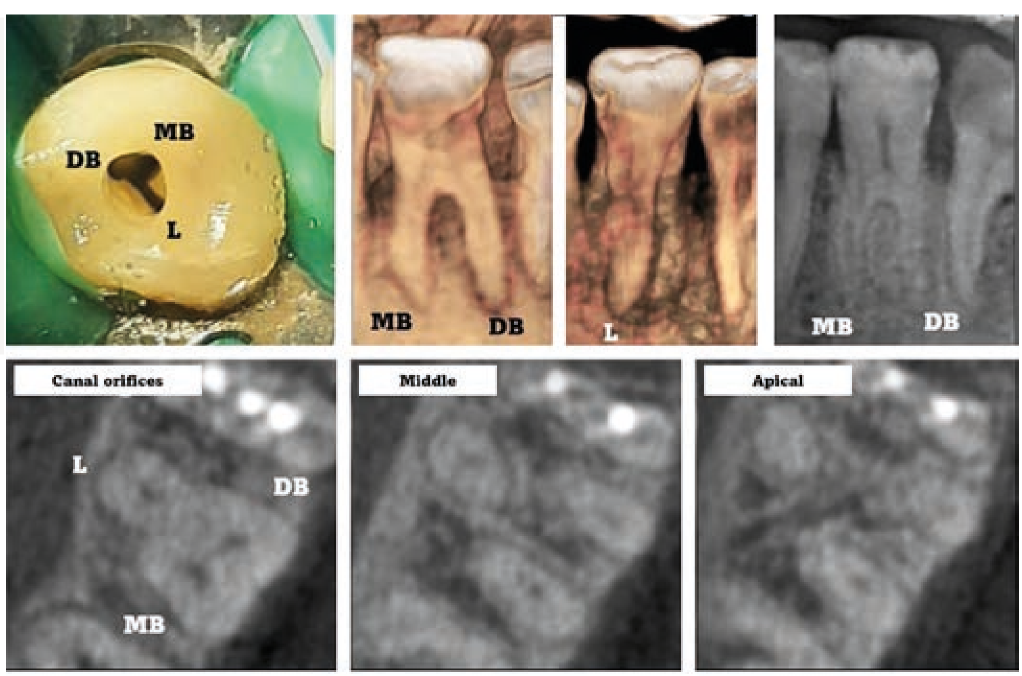


Figure 10
Root canal orifices and CBCT images of the same tooth are in figure 9. CBCT images showed that the tooth had 3 separate roots and canals. There are 2 roots in the buccal and one root in the lingual. The fact that the root canal trifurcation level is in the coronal third facilitates direct access.

tection of at least 2-canal, mesially and distally, on 2D radiographs (Fig. 7 and 9). Lotfi *et al.* (11) defined the presence of a double canal in the distal and a 1-canal in the mesial as teeth with atypical canal orifices. In this type of 3-canal case, the DB and distolingual (DL) canal orifices are in the same direction in the pulpal floor anatomy, and there is a canal orifice on the ML wall (11). Canal orifice distances are

often unequal. The distance between MB-Lingual canals was found to be the longest, and DB-Lingual was the shortest (Fig. 8) (38). Root furcation is mostly located in the middle third (Fig. 10). The average distance of the pulp chamber floor to the CEJ is 5.5 mm. This distance minimizes the risk of perforation during access cavity preparation (38). At root canal furcation levels close to the CEJ, visibility of the canal orifices is easier (Fig. 10).
In 4-canal mandibular premolars, the canal locations were reported to be 2 buccal and 2 lingual canals (2). Five canal cases with double DB, DL, MB, and ML locations have also been observed (10).

Developmental anomalies
Some developmental malformations can be encountered in mandibular premolars, which complicate the root canal anatomy and need to be differentiated. Major anatomical variations such as dens invaginatus, taurodontism, fusion or gemination, and fusion with adjacent supernumerary teeth can be seen in mandibular premolars and may lead to deviations in root canal systems (39,40). Although their incidence in mandibular premolars is low, they should be taken into consideration before treatment.

Coronal and radicular clinical appearance
The evaluation of crown structures before RCT in mandibular premolars and how these features predict root and canal anatomy are unclear. Although the excessive material loss in teeth requiring RCT often makes it difficult to evaluate the coronal properties, an attempt can be made to get an interpretation by examining the crown structures of antimeric teeth due to the high symmetrical involvement in coronal and radicular deviations. Among the dou-

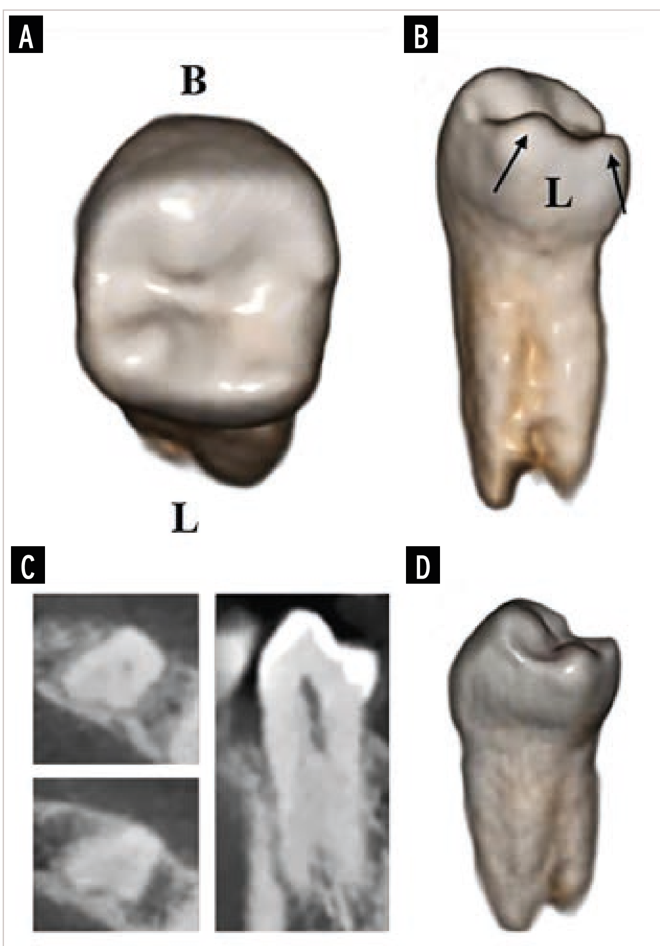


Figure 11
Multiplanar and 3D reconstruction CBCT images of a mandibular second premolar ending in 2 separate roots. **A)** Occlusal view of the tooth. The lingual part of the crown is more voluminous and prominent than the buccal part; **B)** Lingual view of the tooth. Presence of double cusps with an additional cusp increase in the lingual. Radicular structures show integrity in connection with these tubercles. Root structures terminate as double roots in the mesial-distal direction (ASUDAS score 5). Black arrows indicate the lingual cusps; **C)** Atypical radicular and canal morphology is observed in multiplanar CBCT sections; **D)** Proximal aspect of the tooth.

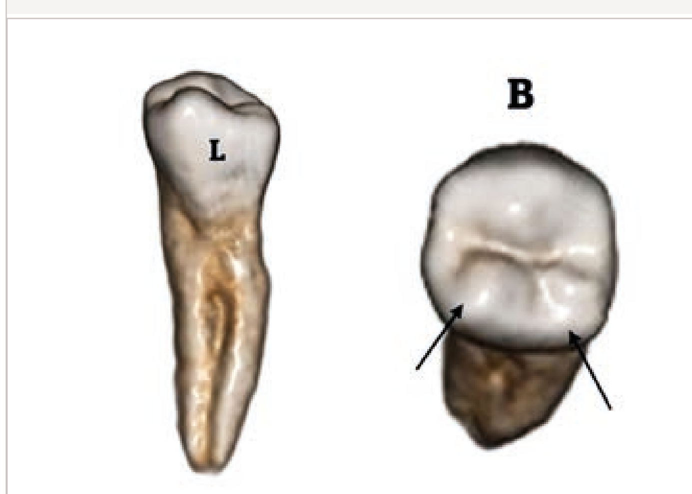


Figure 12
External view of a mandibular second premolar in which the lingual crown structure is more voluminous than the buccal crown structure. The double tubercle on the lingual is supported by prominent root structures and results in the presence of a deep radicular groove on the lingual.

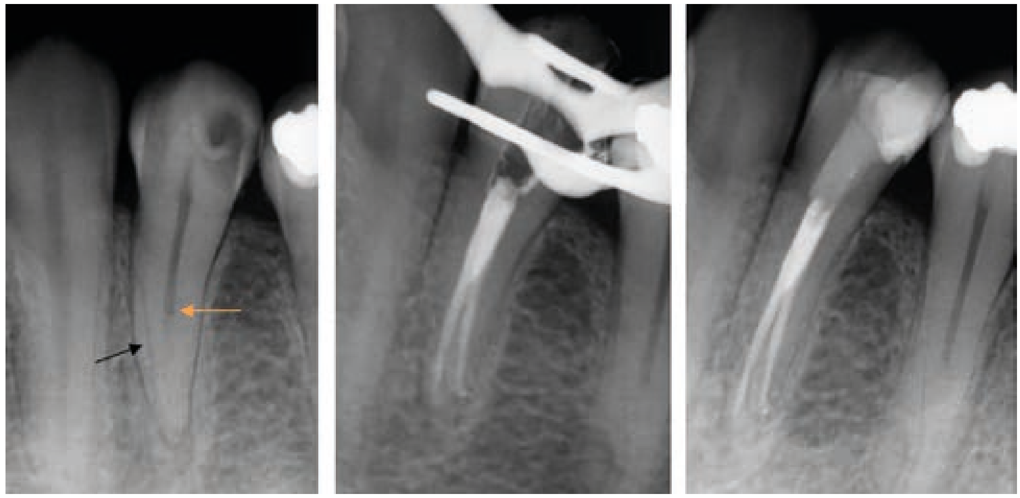


Figure 13
RCT of a 2-canal mandibular first premolar. Initial periapical X-ray shows that the integrity of the root canal is disrupted in the middle third (orange arrow). After this level, the canal is viewed as a single and vague canal. Additionally, the root groove appears as a vertical line on the lateral surface of the rootlack arrow).

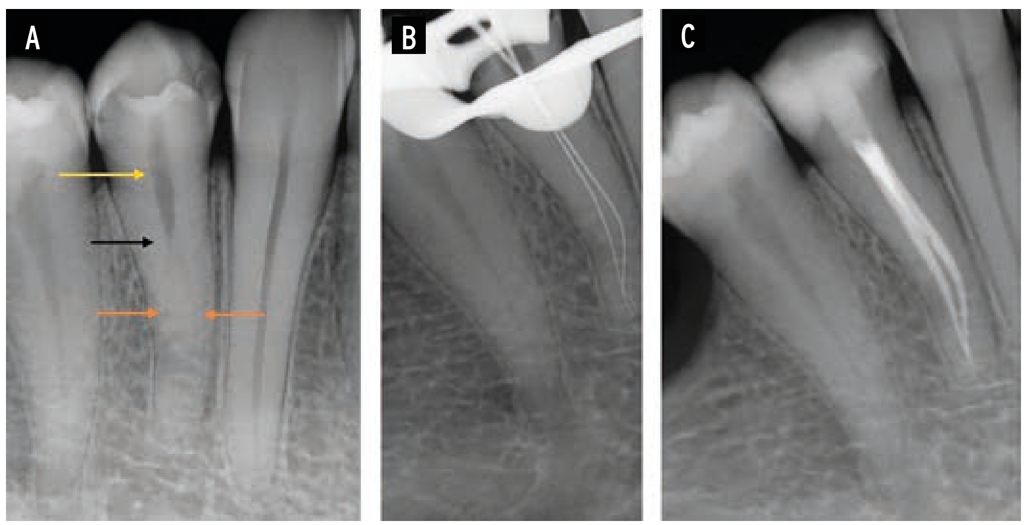


Figure 14
A) Pre-treatment periapical radiograph and **B, C)** RCT of a 2-canal mandibular premolar. When the initial periapical X-ray is examined carefully, the presence of a single distinct canal is viewed after the CEJ (yellow arrow). The canal course disappeared between the coronal and middle thirds (fast-break phenomenon, black arrow). After this point, 2 canals are observed very faintly (Orange arrows). These findings diagnose this tooth as having 2-canal.

ble tubercles found on mandibular premolars, the buccal tubercle is more developed and prominent than the lingual tubercle. One of the features of the ASUDAS mandibular premolar crown is the number of cusps in the lingual region. In some cases, the lingual and buccal tubercles are fused and there is a single tubercle on the tooth. However, there may be cases with 2 or 3 lingual cusps (30). The additional number of cusps in the lingual is observed more in the second premolars (29). However, there is limited information about the deviations of the coronal structures of mandibular premolars with complicated root and canal anatomy from normal variants. Some case reports presented the crown dimensions and the number and development of the occlusal cusps within normal limits and stated that they had typical coronal structures (4,11,37). However, Martins *et al.* (13) pointed out that the incidence of double canals is affected by ethnicity and geographical regions, with the highest rates in Africans and the lowest rates in Asians, and they pointed out that the sizes of the teeth are quite variable between these 2 races. They suggested that larger premolars in Africans may affect the incidence of second canals. Additionally, as shown in figures 11 and 12, it is seen that there are double cusps on the lingual side of the mandibular second premolars, which have 2 separate roots, and this additional cusp is supported by the root structure. Therefore, more caution should be exercised in cases of additional cusps.

Another component that can be evaluated clinically is visual inspection of the roots. If there is gum recession, the presence of

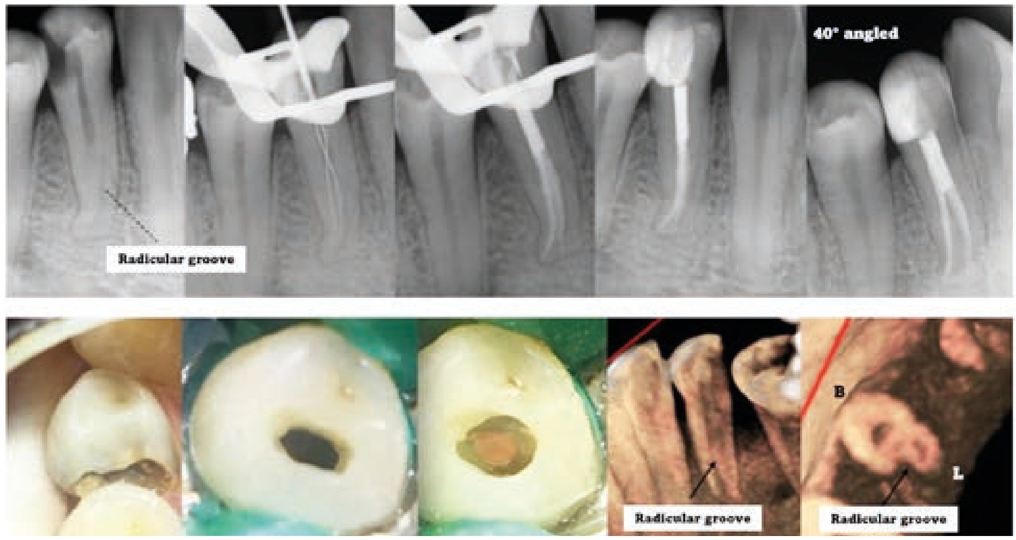


Figure 15
Assessment of the outline of the root and the condition of the periodontal ligament in the initial periapical radiograph can provide information about the general outline of the root. Deep and long radicular grooves can be observed as vertical lines on the radiograph.

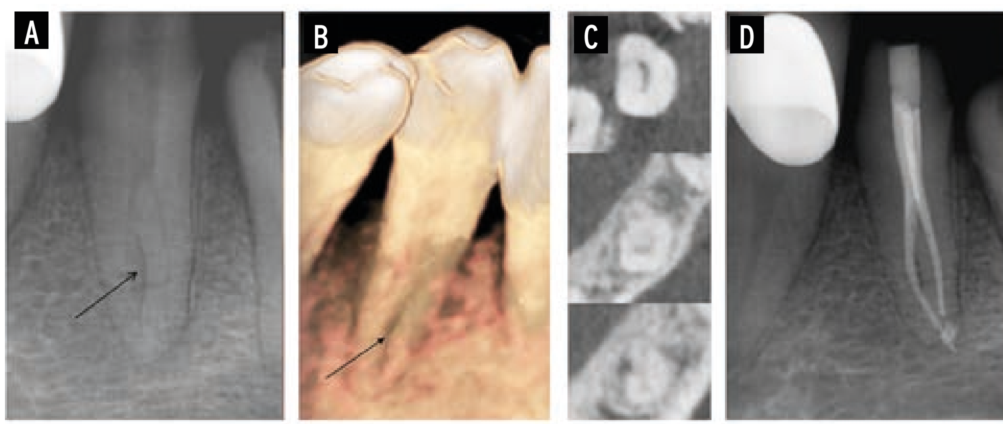


Figure 16
A) Pre-operative periapical radiograph, **B)** 3D reconstruction image, **C)** axial cross-sectional CBCT images in the coronal, middle, and apical thirds, and **D)** post-treatment periapical radiograph of a rotated mandibular first premolar. The rotation of the tooth presented clear indications of the buccal and lingual canals in the pre-operative radiograph (canal bifurcation level is in the middle third, up to this level it is observed in 1-canal radiography). In addition, its rotation caused the radicular groove on the mesial surface (ASUDAS score 3) to be interpreted as a separate canal. In the CBCT images, it is observed that there is a C-shaped canal in the buccal C2 category and a lingual non-C-shaped canal.

furcation in the root can be evaluated. The location of radicular grooves on the proximal surfaces of double-canal teeth may not be beneficial in buccal recessions, but in the presence of more than 1-root, the mesial and distal placement of the roots may make examinations possible.

Radiographic appearance
Since coronal structures do not contribute to every case, the most effective diagnostic tool for root canal multiplicity in mandibular premolars is periapical radiographs. Although the knowledge and skills of endodontists or clinicians are important in successful RCT, multiple canals should be understood by detecting the presence of some radiographic findings. In mandibular bicuspid teeth with complicated root canals, the number, position, shape, and outline of the roots should be assessed on radiography (41). The first rule of radiographic investigation is that the radiographs must be of sufficient quality and taken in the appropriate position. In the next step, knowing which radiographic signs are present will increase the diagnosis of the presence of additional canals (41).
During radiographic examination, the evaluation of root contours and canals must be done separately (42). The presence of a double shadow of the periodontal ligament and the observation of the periodontal ligament space on both sides of the root are features to be evaluated along the contours of the root. Since the root canals in 2-canal mandibular premolars are localized in the BL direction, radiographic assessment of the second canal is not possible in most cases. The superposition of roots and canals can cause problems in the radiographic definition of root canal anatomy (43). The

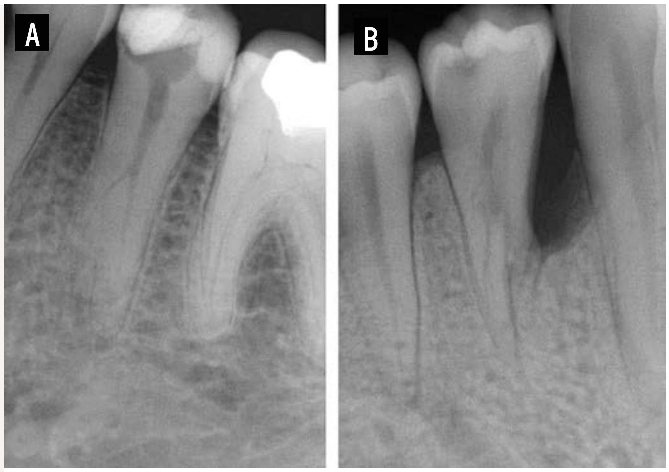


Figure 17
Radiographic views of mandibular premolars with 3-canal. **A)** A mandibular second premolar has an atypical root shape and different root contours. The outer contours of the roots and the tracing of the periodontal ligament indicate the multiple root structures. **B)** A mandibular first premolar in which the furcation level of the roots is observed.

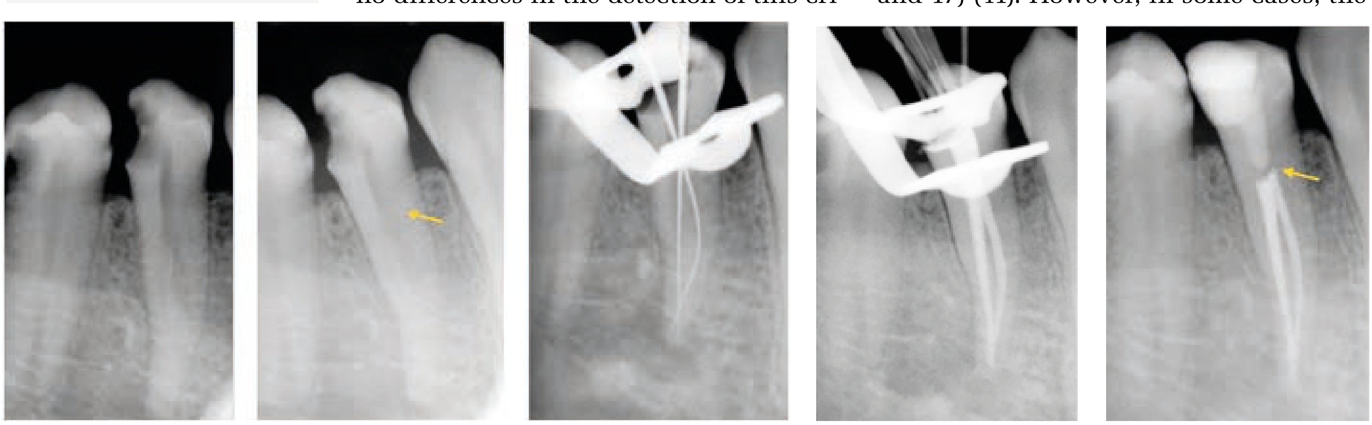
lingual canal is completely or partially overlapped with the buccal canal (44). The most effective way to overcome this problem is to take multiple radiographs from different angles (Fig. 3). Martinez-Lozano *et al.* (43) evaluated canal visualization of mandibular premolars with different horizontal and vertical angles. They reported that horizontal angulation facilitates detection in the second canal and that radiographs taken at a 40° angle are more effective than 20°. They also stated that vertical angulation also had a significant effect.

Some radiographic findings are related to the presence of a second canal. The most typical radiographic finding in these teeth is sudden narrowing or even disappearance of the root canal (45). This finding, described as a *fast break,* is the result of the root canal splitting into 2 or more branches at this point (Fig. 1,7,13,14,18). Sudden canal narrowing is a good radiographic criterion for intricate root canal systems and there are no differences in the detection of this criterion between observers (45). Deviation of the canal to one side during the canal course is another indicator of root canal bifurcation (42). In angled radiographs, the canal bifurcation can be observed in the BL direction. In some cases, after the fast break phenomenon, the canal becomes less clear and faint (Fig. 13) or can be observed as 2 faint canals (Fig. 14).

The high prevalence of multiple canals in mandibular premolars with radicular grooves makes it important to examine this anatomical formation on radiography (Fig. 5,6,13,15,16). Radicular grooves usually present as a radiolucent parapulpal line on X-ray. This parapulpal line can be observed longitudinally (Fig. 15). When the radicular groove is observed, the presence of a second canal should be considered more comprehensively. However, in some cases, it can be perceived as a separate canal and may suggest the presence of a third canal in a double-canal tooth (Fig. 16).

In mandibular premolars with 3 or more canals, signs of apical separation of the roots and sudden changes in the radiographic density of the root canal in the middle and apical thirds are observed in the radiography (Fig. 7) (2). If there are 3 separate canals within a 1-root, multiple weak radiolucent lines may be seen within a 1-root (46). Radiographic signs of teeth with 2/3 roots or 3 canals are in most cases more pronounced than those of teeth with 2 canals (Fig. 9 and 17) (41). However, in some cases, the

Figure 18
In a complicated canalled mandibular premolar, the root canal bifurcation level in the coronal third is a factor that facilitates the detection and treatment of the canals. The yellow arrow shows the bifurcation point of the canals.



superposition of roots in a narrow area may prevent the viewing of all root canals (41). Zoya-Farook *et al.* (9) stated that the radiographic appearance of the 3-canal case appeared bulbous. Atypical root shapes and different root contours indicate the additional number of roots.

In cases where clinical and radiographic findings cannot provide a clear interpretation, CBCT provides more advanced root and canal configuration information (Fig. 1,3,5-7,10,16). The 3D structure of CBCT and its elimination of the superposition of surrounding tissues enable us to understand features such as the number of roots and canals and the presence of merging in the canals before treatment (1). In a study (47) of premolars, CBCT imaging was significantly more accurate than periapical radiography in determining root canal anatomy. If the indication criteria are observed, CBCT is the most clinically effective method in the diagnosis of root and canal anatomy.

Access cavity and negotiation of canals

Multiple canals can be understood with some findings intra-operatively in mandibular premolars, where an interpretation is provided clinically and radiographically. Another factor that increases the difficulty in the RCT of mandibular bicuspids with multiple root canal systems is the limited field of visualization due to the relatively small size of the access cavities (2). It is not easy to explore and manage the canals in small access cavity preparations in the mesiodistal direction (2). The most important supporting equipment in the treatment of mandibular premolars with complicated root canals is the use of magnification tools (46). In this way, deeply split root canals can be scouted not only with imagination but also visually (12). The overall quality and success rate of the treatment is increased. Careful inspection and observation of the pulp chamber floor and walls reduce errors (10).

In both 1- and 2-canalled mandibular premolars, the root canals start as a 1-canal orifice. The most common canal orifice shape is an oval form. This is followed by flattened-ribbon shape, eight-shaped, and triangular 1-canal orifice shapes, respectively (35). However, there are no significant differences between the canal orifices of double and 1-canalled teeth, making the detection and treatment of the lingual canal difficult.

In 2-canal teeth, the canals are in the BL direction and the split points are mostly in the middle third, with less apical and coronal division (44). It is easier to find canals in separations close to the coronal third (Fig. 3 and 18). In root canals that have a deep bifurcation in the middle and apical thirds, it becomes difficult to detect the lingual canal. The buccal canal is the canal that is large, and the canal instrument moves straight through. The lingual canal is the canal that is more difficult to scout, explore, and prepare. When the lingual canal is separated at a sharp angle, an image resembling the letter 'h' is formed in the coronal section of the 2-canal (Fig. 19).

It has been suggested to enlarge the pulp chamber with Gates-Glidden burs to facilitate better observation and detection of the canal orifices (9). It is a common procedure to use a pre-curved K-file over the root canal walls with tactile examination and capture a catch point. There have been clinicians reporting that the use of dyes such as methylene blue is beneficial (8). It has been suggested that in teeth with 3 or more canals, placing a small amount of calcium hydroxide at the bifurcated dentin point increases vision in the root canals and facilitates canal exploration (10). Sodium hypochlorite bubbling test and observation of bleeding points are other useful methods (48).

In teeth with 3-canal, the canal orifices deviate from the normal BL direction and are not in a straight direction. The presence of a third canal should be suspected in the pulp chamber floor deviating from the normal anatomy in a triangular shape or a wider form in the MD direction. It is crucial to understand the topographic location of the furcation and determine the location of the canal orifices (8). Anatomical landmarks of the pulp chamber floor can help in the diagnosis of complex

Figure 19
In mandibular premolars with 2-canal, the buccal canal continues straight. The lingual canal is separated from the main canal at a certain angle. In some cases, this angle can be very sharp and is named the *'h'* canal.

root canals. Black spots should be observed on careful examination of the pulpal floor and walls. Interpretation of the pulp floor map is useful in diagnosing all canals.

Root canal preparation

In mandibular premolars with 2-canal, the buccal canal is wider and considered the main canal. The lingual canal is separated from the main canal at a sharp angle of approximately 34° (44). While the lingual canals are straight from the lingual view, they are mostly bifurcated from the proximal view at a severe angle (44). There are cases where this angle is 65° (44). Additionally, the lingual canal is often curvature. Although coronal flaring is recommended in the lingual canal to reduce curvature (44), Gu et al. (34) pointed out the thinness of the dentin thickness in the lingual region and recommended conservative shaping in the lingual canal, as excessive removal of dentin in the coronal region would weaken the root. There is only 1 study (49) in the literature that evaluates the root canal instrumentation of mandibular premolars with radicular grooves and a lingual canal. In this study, ProTaper Next (PTN) and XP-endo Shaper (XPS) systems were compared. With XPS, less apical canal transport and more remaining dentin thickness were achieved in the lingual canal. No difference was observed after preparations in the buccal canal. In the lingual section, attention was drawn to the thinness of the dentin, and it was emphasized that it could be a danger zone. Lower taper systems have been recommended to prevent the risk of perforation and root fracture. Using fresh instruments and observing distortions on the files will reduce the possibility of fracture (46).

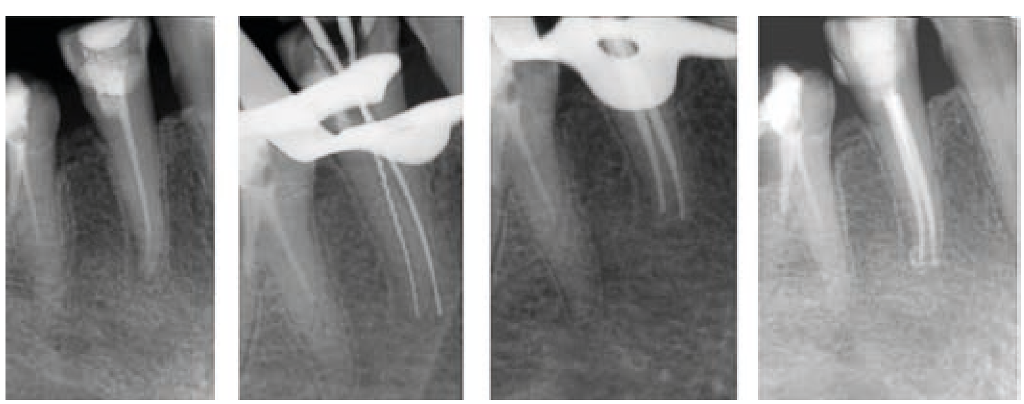
Retreatment

The possibility of the presence of second or third canals should be considered in endodontic failure of mandibular premolars (Fig. 20). Lack of treatment for additional root canals is one of the major factors in the development of apical periodontitis. In mandibular premolars with a complex root canal system, some signs are examined to diagnose the missed canal. In some cases, the presence of the untreated canal is visible on the radiography (Fig. 21). In some cases, the second canal may be seen, although less clearly (Fig. 22).
Another sign of the presence of a missed lingual canal in mandibular premolars that previously performed RCT is the eccentric placement of the canal filling in the treated buccal canal (Fig. 23 and 24). Since the canal is in the center of the root in 1-canalled mandibular premolars, root canal filling is seen in the center of the root in straight and angled radiographs. Root canal filling located towards 1 side of the root is a clue that only one canal has been treated.

Conclusion

Complicated root and canal patterns are frequently encountered in mandibular premolars. Some clinical and radiograph-

Figure 20
One of the major causes of endodontic failure in mandibular premolars is untreated lingual canals.



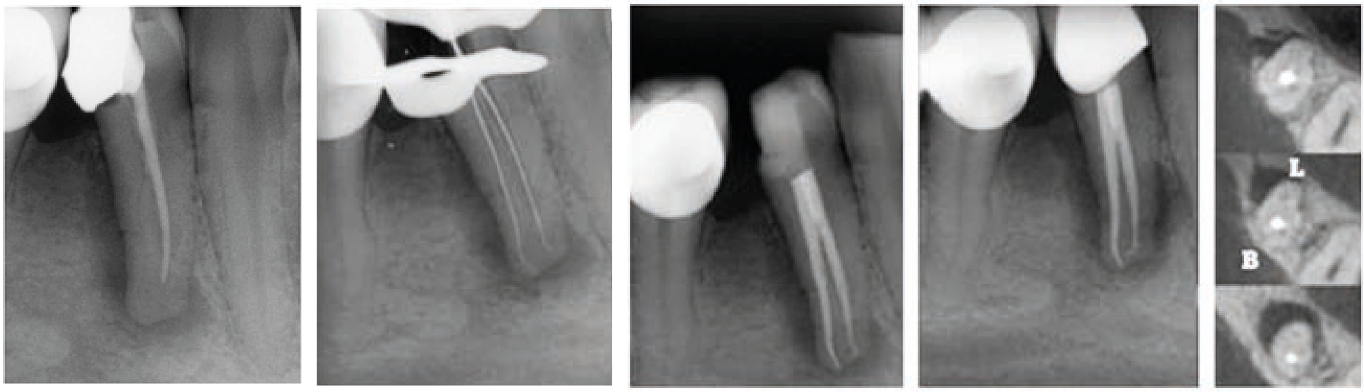


Figure 21
RCT of a mandibular second premolar with 2 canals in which the lingual canal is omitted. The lingual canal can be observed on the pre-treatment radiography.

ic signs should be evaluated to diagnose supplemental root canal configurations. In teeth with wider crown widths, the number of roots and canals and the possibility of exhibiting complex canal features may increase. Lingual tubercle variations (absence of tubercle in the lingual region, presence of 1-, 2-, or 3-tubercle in the lingual, and size differences of buccal/lingual tubercles) may be indicators of root canal multiplicity. There are significant correlations between radicular grooves and a variety of root canal configurations. Moreover, a broad spectrum of morphological deviation and a C-shaped root canal system are observed in mandibular premolars with radicular grooves. Radicular grooves usually present as a radiolucent parapulpal line on radiograph. Periapical radiography is the one of the most effective diagnostic methods for mandibular premolar root canal abnormalities. The presence of a double shadow of the periodontal ligament and the observation of the periodontal ligament space on both sides of the root are features to be evaluated along the

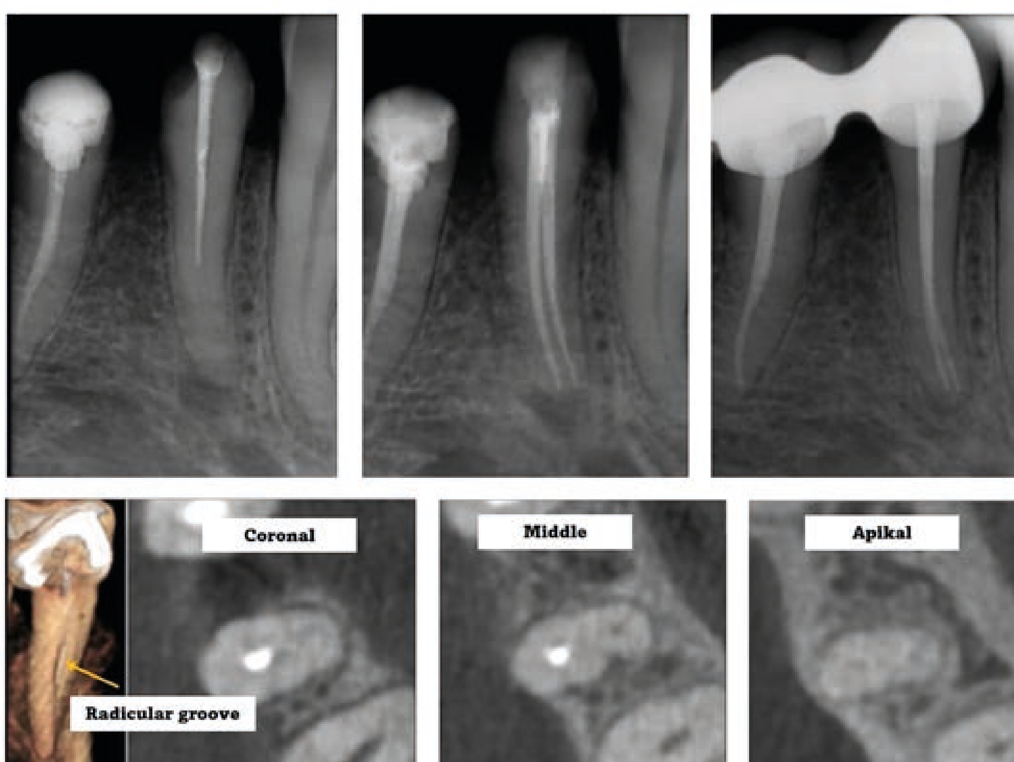


Figure 22
A mandibular first premolar that treatment of the lingual canal was missed. In the initial periapical X-ray, after the incomplete gutta-percha level, both canals can be observed as vague.

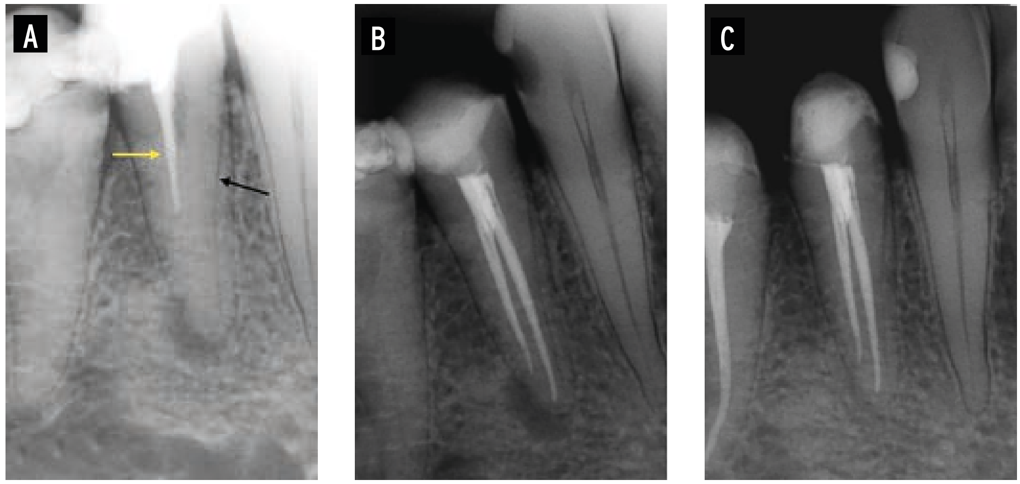


Figure 23
Retreatment of a mandibular first premolar. **A)** Initial periapical radiograph, **B)** post-operative periapical radiograph, and **C)** 6-month follow-up. In the initial periapical radiograph, the eccentric location of gutta-percha (yellow arrow) and the radicular groove (black arrow) are signs of the presence of the second canal.

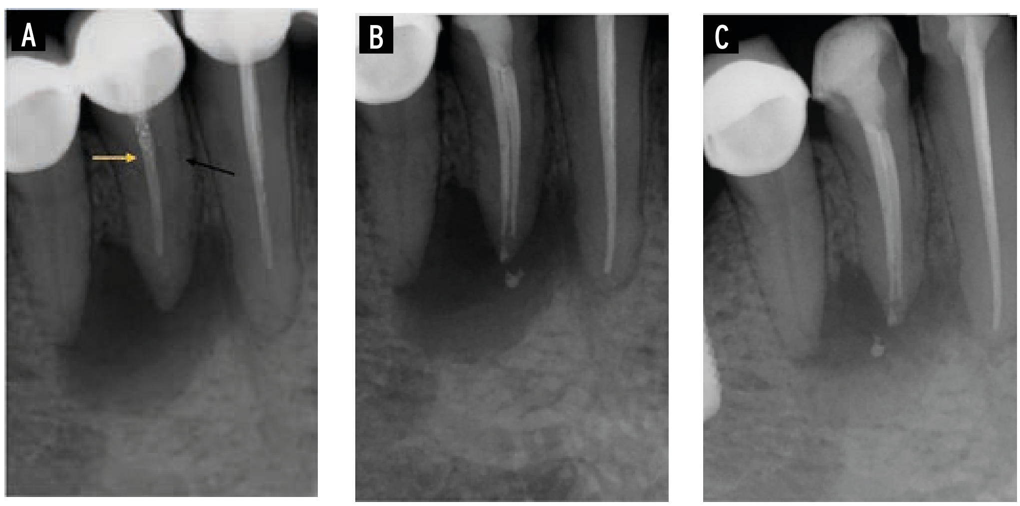


Figure 24
RCT of the mandibular first premolar with a large cyst-like periapical lesion. **A)** Pre-operative X-ray, **B)** post-operative X-ray, and **C)** 3-month follow-up film. Initial periapical radiograph shows inadequate and eccentrically located canal filling. Eccentric placement of gutta-percha is a finding observed in 2-canal teeth (yellow arrow). Additionally, the presence of a radicular groove is another radiographic sign (black arrow). These findings indicate the existence of a second canal.

contours of the root. Taking multiple radiographs from different angles, sudden narrowing or even disappearance of the root canal, and the eccentric position of the root canal files are important radiographic findings. Additionally, CBCT method can provide more specific information regarding the teeth. As a result, to recognize complicated root canal morphology will enhance the reduction of endodontic treatment iatrogenic errors and mishaps.

Clinical Relevance

In mandibular premolars, the presence of a complicated root canal system can be understood before or during root canal treatment with comprehesive information and careful clinical and radiographic examinations.

Conflict of Interest

The authors declared no conflict of interest.

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  22 GIUGNO SESSIONE SCIENTIFICA APERTA A TUTTI
- **ROMA** 39° CONGRESSO NAZIONALE SIE

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  9 APRILE ORE 20.30

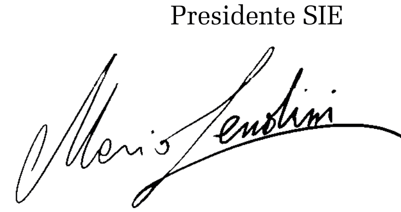
  4 GIUGNO ORE 20.30

  10 SETTEMBRE ORE 20.30
- **FAD SIE AIE**
- **20 EVENTI MACRO AREE**

Lettera DEL PRESIDENTE

Cari Amici, Soci e Colleghi,
Sono molto felice e orgoglioso, a nome di tutta la Società Italiana di Endodonzia, di poterVi annunciare finalmente il raggiungimento di un importante obiettivo a lungo ricercato: la nostra rivista, il Giornale Italiano di Endodonzia, ha ottenuto l'Impact Factor (IF) lo scorso giugno.
Questo importante riconoscimento è frutto di molti anni di lavoro dei Presidenti che mi hanno preceduto, insieme con i loro Consigli Direttivi, degli Editor in Chief, in particolare di Sandro Rengo, che da molti anni ricopre questo difficile incarico, e della nostra casa editrice Ariesdue, principalmente nella persona del Managing Director Simone Porro.
Il lavoro specifico di tante persone come quelle che ho citato, insieme a tante altre, meno appariscenti, ma ugualmente importanti, è stato ovviamente necessario e fondamentale, ma permettetemi di affermare che questo successo è principalmente merito di tutta la SIE nella perseveranza dell'impegno nella propria Mission di creare cultura e divulgazione scientifica di altissimo profilo, non solo italiano, ma con respiro internazionale.
La SIE non è un'entità astratta, è un coacervo di menti, di impegno e di passioni, rappresentate da tutti noi Soci, da personalismi e da sinergie, da contrasti, anche accesi, ma sempre rispettosi dell'altrui pensiero, che in oltre quaranta anni di evoluzione ci hanno portati fino ad oggi attraversando molte difficoltà.
Nel 1970, su ispirazione di alcuni menti che guardavano lontano, nasce il Gruppo di Studio di Endodonzia. Lo Statuto da loro stilato recitava: "Lo scopo di questo gruppo è quello di facilitare ai singoli componenti l'acquisizione e l'accrescimento delle proprie nozioni, mediante lo scambio di opinioni, esperienze, informazioni ecc.".
Su questa base, nel 1974 è stata fondata la Società Italiana di Endodonzia, di cui quindi ricorrerà nel 2024 il cinquantenario della fondazione.
La SIE, in tutti questi anni, si è evoluta ed è cambiata, a volte bene e a volte con maggiore difficoltà, per adeguarsi ai tempi e alle necessità della nostra specialità e dei Soci, ma è sempre riuscita a mantenere intatta la sua identità e a portare avanti la sua Mission.
Le auto-celebrazioni sono confortanti, ma diventano sterili quando sono fini a sé stesse. Sono sicuro che voi condividete con me la certezza della necessità di progredire inSIEme sempre con nuove idee, nuovi obiettivi, nuove ricerche e nuove condivisioni con il fine di una crescita comune.
L'attuale valore di I.F. conseguito, 0.4, non è un punto di arrivo, bensì una base di partenza per far crescere l'importanza della rivista e il peso della nostra Società.
Possiamo farlo, noi tutti, in molti modi: il primo è certamente quello di inviare articoli – considerate che attualmente solo il 33% sono di autori italiani –, ma anche, molto importante, citando, sia sul GIE sia su altre riviste, articoli da noi pubblicati; non ultimo, mi rivolgo in particolare ai tanti Soci docenti universitari, diffondendo la consultazione del GIE fra gli studenti e i Colleghi per i loro approfondimenti e per le loro ricerche.
Ricordo anche che il vincitore del nostro prestigioso premio per la ricerca "Riccardo Garberoglio", oltre al premio in denaro, ha il diritto e l'obbligo di pubblicazione sul GIE.
Vorrei ancora fare i complimenti a due nostri Soci che rappresentano la SIE in campo internazionale con grande prestigio: Elisabetta Cotti, Presidente Eletto dell'IFEA (International Federation of Endodontic Associations) e Gianluca Gambarini, Presidente Eletto dell'ESE (European Society of Endodontology). A nome di noi tutti i migliori auguri di buon lavoro!
Avremo modo di ascoltarli nell'inaugurazione e nelle loro relazioni al 38 Congresso Nazionale del 9, 10 e 11 novembre a Bologna.
Sicuro di rivederVi al nostro congresso e di interpretare il pensiero di tutti, vorrei ringraziare il Consiglio Direttivo, i Responsabili di Macro Area, tutte le Commissioni e i Soci che hanno lavorato e lavorano per la SIE.
Un affettuoso saluto

Mario Lendini
Presidente SIE



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Davide Castro
Via Oioli, 6/B
28013 Gattatico (NO)
Tel. 0331-735276
cel. 338 7075126
davidefabio.castro@gmail.com

COORDINATORI MACROAREE IN CARICA NEL BIENNIO 2023-24

SIE MacroArea
Nord-Est

Chiara Pirani
Via Carlina, 12/2
40055 Castenaso (BO)
Tel. 051 6494868
cel. 347 0961012
clairepirani@hotmail.com

SIE MacroArea
Nord-Ovest

Lucia Reggio
Via San Secondo, 38
10128 Torino (TO)
Tel. 011 6610818
cel. 333 1927067
lucia.reggio84@gmail.com

SIE MacroArea
Centro

Alessandra D'Agostino
Via Bellini, 5
03043 Cassino FR
tel. 0776 312378
cell. 328 3071792
alessandradagostino74@gmail.com

SIE MacroArea
Sud

Massimo Calapaj
Via N. Panoramica dello Stretto, 480
98168 Messina (ME)
Tel. 090 661462
cel. 333 2193009
calapaj.massimo@gmail.com

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COME DIVENTARE SOCIO ATTIVO/AGGREGATO

Scaricabile dal sito **www.endodonzia.it**

SOCIO AGGREGATO

Per avere lo status di Socio Aggregato si dovrà presentare la documentazione descritta nel sito www.endodonzia.it che sarà valutata dalla Commissione Accettazione Soci. La documentazione che verrà presentata dovrà mostrare con rigore, attraverso casi clinici, l'interessamento del candidato alla disciplina endodontica.
Un meccanismo a punti è stato introdotto per valutare l'ammissibilità del candidato allo "status" di Socio Aggregato: i punti saranno attribuiti in base al tipo di documentazione presentata. Possono accedere alla qualifica di Socio Aggregato tutti i Soci Ordinari della SIE, in regola con le quote associative degli ultimi tre anni, che completino e forniscano la documentazione alla Segreteria Nazionale (Via Pietro Custodi 3, 20136 Milano) entro i termini che verranno indicati all'indirizzo web: www.endodonzia.it.
La domanda dovrà essere firmata da un Socio Attivo, in regola con la quota associativa per l'anno in corso, il quale è responsabile della correttezza clinica e formale della documentazione presentata.

DOCUMENTAZIONE NECESSARIA PER DIVENTARE SOCIO AGGREGATO

Qualsiasi Socio Ordinario, con i requisiti necessari, può presentare la documentazione per ottenere la qualifica di Socio Aggregato. Un meccanismo a punti è stato introdotto per valutare il candidato: un minimo di 80 punti è richiesto per divenire Socio Aggregato.
La documentazione clinica per ottenere la qualifica di Socio Aggregato dovrà presentare almeno sei casi, di cui non più di tre senza lesione visibile nella radiografia preoperatoria e non più di uno di Endodonzia Chirurgica Retrograda.
Nella domanda non potranno essere presentati casi la cui somma superi i 120 punti per la qualifica di Socio Aggregato.
L'aspirante Socio Aggregato potrà presentare la documentazione clinica in più volte, con un minimo di 40 punti per presentazione, in un arco massimo di tre anni. Il mancato rinnovo della quota associativa, anche per un solo anno, annulla l'iter di presentazione dei casi.

SOCIO ATTIVO

Per avere lo status di Socio Attivo si dovrà presentare la documentazione descritta nel sito www.endodonzia.it che sarà valutata dalla Commissione Accettazione Soci. La documentazione che verrà presentata dovrà mostrare con rigore, attraverso documentazione scientifica e casi clinici, l'interessamento del candidato alla disciplina endodontica.
Un meccanismo a punti è stato introdotto per valutare l'ammissibilità del candidato allo status di Socio Attivo: i punti saranno attribuiti in base al tipo di documentazione clinica e scientifica presentata. Possono accedere alla qualifica di Socio Attivo tutti i Soci Ordinari della SIE, in regola con le quote associative degli ultimi tre anni, che completino e forniscano la documentazione alla Segreteria Nazionale (Via Pietro Custodi 3, 20136 Milano) entro i termini che verranno indicati all'indirizzo web: www.endodonzia.it.
La domanda di ammissione allo status di Socio Attivo rivolta al Presidente della SIE dovrà essere firmata da un Socio Attivo in regola con la quota associativa per l'anno in corso, il quale dovrà aver esaminato e approvato la documentazione. Quest'ultimo è responsabile della correttezza clinica e formale della documentazione presentata.

DOCUMENTAZIONE NECESSARIA PER DIVENTARE SOCIO ATTIVO

Qualsiasi Socio Ordinario, con i requisiti necessari, può presentare la documentazione per ottenere la qualifica di Socio Attivo. Il Socio Aggregato che volesse presentare la documentazione scientifica e clinica a integrazione di quella clinica già approvata dalla CAS per lo status di socio Aggregato, potrà farlo già dall'anno successivo all'ottenimento della sua qualifica.
Un meccanismo a punti è stato introdotto per valutare il candidato a Socio Attivo. Un minimo di 200 punti è richiesto per divenire Socio Attivo.
Nella domanda non potranno essere presentati casi la cui somma superi i 240 punti per la qualifica di Socio Attivo.
La documentazione scientifica potrà essere presentata, a completamento della documentazione clinica, solo per la domanda per divenire Socio Attivo e non potrà superare i 80 punti.
La documentazione clinica dovrà presentare un minimo di sei casi, di cui almeno 4 di molari pluriradicolati con delle precise tipologie: tra questi casi almeno uno deve essere un ritrattamento con lesione visibile nella radiografia preoperatoria e dei restanti tre almeno due devono avere una lesione visibile nella radiografia preoperatoria.
La documentazione clinica non deve presentare più di un caso di Endodonzia Chirurgica Retrograda con immagini e non più di uno senza immagini.
La documentazione scientifica non potrà presentare più di due articoli come coautore.

MODALITÀ DI DOCUMENTAZIONE DEI CASI CLINICI

Criteri e modalità per la valutazione dei casi clinici idonei ad accedere alle qualifiche di Socio Aggregato e di Socio Attivo sono espressi nell'apposita sezione del Regolamento della Società Italiana di Endodonzia (SIE) all'indirizzo web: www.endodonzia.it.

CRITERI DI VALUTAZIONE

I casi clinici verranno valutati nel loro complesso, coerentemente con gli scopi e fini della SIE, e devono essere presentati dai Candidati considerando non solo l'aspetto clinico, ma anche quello formale della documentazione presentata.
La documentazione scientifica verrà valutata considerando la classificazione ANVUR delle Riviste Scientifiche, i documenti scientifici dovranno essere tutti di pertinenza endodontica.

ADEMPIMENTI DEL CANDIDATO

La domanda di ammissione allo status di Socio Aggregato/Attivo, rivolta al Presidente della SIE, dovrà pervenire, insieme alla documentazione di seguito elencata, alla Segretaria della SIE con un anticipo di 20 giorni sulle date di riunione della CAS, sufficiente per poter organizzare il materiale dei candidati. Le date di scadenza saranno rese note sul sito. La domanda dovrà essere firmata da un Socio Attivo in regola con la quota associativa per l'anno in corso, il quale dovrà aver esaminato e approvato la documentazione. Quest'ultimo è responsabile della correttezza clinica e formale della documentazione presentata.

PRESENTAZIONE DEI CASI ALLA COMMISSIONE

La presenza del Candidato è obbligatoria durante la riunione della CAS; è altresì consigliabile la presenza del Socio presentatore.

LA COMMISSIONE ACCETTAZIONE SOCI

La CAS (Commissione Accettazione Soci) è formata cinque Membri di indiscussa esperienza clinica, quattro Soci Attivi con almeno cinque anni di anzianità in questo ruolo eletti a ogni scadenza elettorale dall'Assemblea dei Soci Attivi e Onorari e uno dei Past President della Società incaricato dal CD a ogni riunione. Compito della CAS è quello di esaminare e valutare la documentazione presentata dagli aspiranti Soci Aggregati e Soci Attivi. Per rispetto del lavoro dei Candidati e per omogeneità di giudizio, in ogni riunione CAS verranno valutati non più di 12 candidati a Socio Attivo; resta libero, invece, il numero dei candidati a Socio Aggregato valutabile in una singola riunione. Il Consiglio Direttivo (CD) incaricando la Commissione Accettazione Soci (CAS) la rende responsabile dell'applicazione delle regole descritte nell'articolo 2 del regolamento. Il giudizio della CAS è insindacabile.

MEMBRI DELLA COMMISSIONE ACCETTAZIONE SOCI BIENNIO 2023-24

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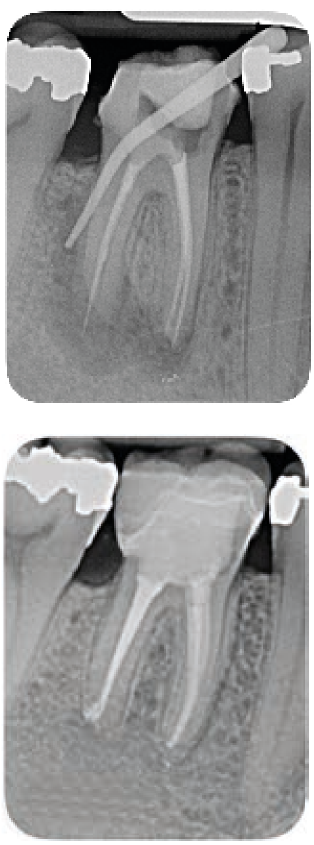
Marco Colla
Claudia Dettori
Giuseppe Multari

CeraSeal

Quality and ergonomics
for simple and predictable root canal fillings



Courtesy
of Dott. Filippo Cardinali

Role and aims of root canal obturation

Complete filling of the endodontic space combined with an airtight seal of the foramen are essential prerequisites for a quality root canal obturation and represent the goal the clinician must aspire to when performing the obturation.
Pre-mixed bioceramic cements for root canal fillings have been in use in clinical practice for more than 10 years and their use is becoming increasingly popular due to their characteristics. The absence of shrinkage and the interaction with the canal walls during the hardening reaction allow the clinician to achieve the obturation goals using cold gutta-percha techniques, which are easier and faster to perform than hot techniques.

Ceraseal: ergonomics and safety

Ceraseal is a pre-mixed calcium-silicate bioceramic cement that can be easily applied inside the canal with disposable tips: the absence of powder-liquid mixing phases means that the cement components are in the ideal percentages, eliminating the risk of contamination during preparation and insertion of the cement into the canal.
Ceraseal has a high radiopacity that makes it clearly visible on post-operative X-rays. During the setting reaction, high pH values are reached, giving Ceraseal a powerful antibacterial action.

Hermetic Seal

Ceraseal requires moisture to start the setting reaction, which results in a chemical bond between the bioceramic cement and the dentin of the canal parts. This chemical reaction also occurs within the dentinal tubules where Ceraseal can penetrate due to its low particle size, resulting in a high-quality hermetic seal that prevents bacteria from percolating into the canal. The ability to harden in a moist environment makes Ceraseal the cement of choice when complete drying of the endodontic system is not possible for anatomical reasons.

Flowability and Stability

The high fluidity allows Ceraseal to penetrate even unshaped spaces such as isthmuses or lateral canals and fill the endodontic system three-dimensionally. Ceraseal does not contract or expand: this unique stability is the basis for its use with cold gutta-percha techniques such as single cone, not to mention that it can also be used with conventional hot root canal techniques.

Biocompatibility and Bioactivity

Biocompatibility is certainly one of the most important features of Ceraseal: in case of accidental extrusion, Ceraseal does not interfere with the health status of healthy periapical tissues, nor does it interfere with healing processes in case of periapical lesions, promoting instead peri radicular bone regeneration.

ApicalShaper

L'ultima generazione di strumenti per la sagomatura apicale

ApicalShaper® è la soluzione all'avanguardia per la sagomatura apicale dei canali radicolari.

Questo sistema innovativo è compatibile con tutti i sistemi di sagomatura canalare presenti sul mercato, garantendo un'efficacia senza precedenti.

Uno dei principali vantaggi di ApicalShaper® è la sua conicità del 3%, caratteristica che permette l'allargamento apicale fino al 50% in più, mantenendo inalterata la precedente sagomatura del 3° medio e del 3° coronale. Inoltre, questa conicità ridotta permette di preservare al meglio la dentina pericervicale, garantendo la massima protezione.

Grazie alla sua eccezionale conicità, ApicalShaper® permette anche di portare più volume di irrigante, il sistema assicura quindi una pulizia profonda e completa del canale radicolare, contribuendo a eliminare efficacemente i batteri e i residui presenti.

La lega Blu utilizzata per la produzione di ApicalShaper® offre la massima flessibilità e resistenza alla fatica ciclica. Ciò significa che gli strumenti sono in grado di sopportare un utilizzo prolungato senza perdere efficacia. Inoltre, il design con sezione trasversale a parallelogramma centrato garantisce un'ottima capacità di taglio, consentendo una sagomatura precisa e accurata del canale radicolare.

La gamma ApicalShaper® offre una vasta scelta di strumenti, permettendo allo specialista di selezionare quello più adatto alle sue esigenze cliniche. I quattro strumenti disponibili, 30/03, 35/03, 40/03 e 50/03, offrono una varietà di opzioni per garantire risultati ottimali in ogni situazione.

Scegli ApicalShaper®, il sistema all'avanguardia per la sagomatura apicale che garantisce risultati eccellenti. Non solo migliora l'efficienza del tuo lavoro, ma assicura anche la massima protezione per i denti dei tuoi pazienti. Prova ApicalShaper® oggi stesso e scopri la differenza che può fare nella tua pratica odontoiatrica.

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EdgeEndo

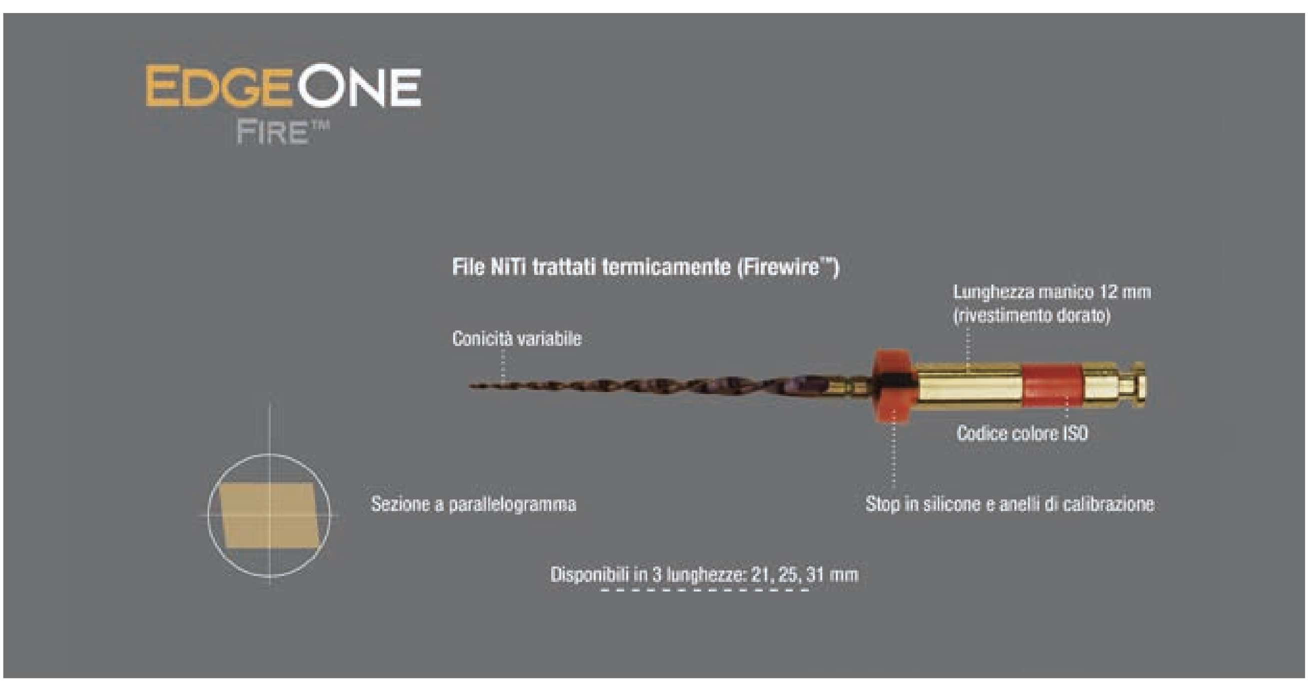
PERFORMANCE. PRICE. TECHNOLOGY.

EdgeEndo offre prodotti e soluzioni endodontiche di altissima qualità con tecnologie all'avanguardia e un ottimo rapporto qualità/prezzo.
Con le linee **EdgeTaper, EdgeTaper Platinum, EdgeOne Fire, EdgeFire X7,** i file EdgeEndo garantiscono velocità e sicurezza nel trattamento endodontico e grandi vantaggi sia per gli operatori che per i pazienti.
L'applicazione alla strumentazione rotante della nuova tecnologia **FireWire™** rende il file più flessibile incrementandone la resistenza alla fatica ciclica, elimina la memoria elastica preservando l'anatomia del canale e la dentina e permette allo strumento di seguire con precisione il percorso canalare in modo semplice ed efficace.
La linea di file reciprocanti EdgeOne Fire riduce il numero di strumenti necessari per la sagomatura, presenta un design conico variabile che riduce il diametro massimo delle spire (MFD) e l'effetto di avvitamento e grazie al nuovo trattamento FireWire™ gli strumenti risultano due volte più resistenti alla fatica ciclica rispetto agli altri.

La parola ai clinici che usano con grande soddisfazione i file EdgeEndo

"Ho recentemente paragonato i file **EdgeEndo NiTi** alla mia sistematica attuale. Sono stato piacevolmente sorpreso dalla loro flessibilità, durevolezza e resilienza alla rottura. Vantaggio più importante per me è stato poter conservare la mia tecnica ottenendo un identico risultato e risparmiando denaro. EdgeEndo è entrato a far parte della quotidianità del mio protocollo clinico."
Prof. Gianluca Gambarini, Università La Sapienza, Roma

"A mio parere X7 è il miglior sistema di file rotanti per la terapia endodontica mininvasiva. L'esclusivo trattamento termico e il diametro ridotto delle spire conferiscono maggiore efficienza e sicurezza nei casi complessi."
Prof. Gianluca Gambarini, Università La Sapienza, Roma



Per info
Dental Trey srl | Via Partisani, 3 | 47016 Fiumana-Predappio (FC), Italia
T +39 0543 929111 | F +39 0543 940659 | **www.dentaltrey.it | commerciale@dentaltrey.it**

GUIDELINES FOR AUTHORS

Giornale Italiano di Endodonzia (GIE) was founded in 1987 and is the official journal of Società Italiana di Endodonzia, SIE (Italian Society of Endodontics) https://www.endodonzia.it/

It is a peer-reviewed journal, only available in electonic format and publishes original scientific articles, reviews, clinical articles and case reports in the field of Endodontology. Scientific contributions dealing with health, injuries to and diseases of the pulp and periradicular region, and their relationship with systemic well-being and health. Original scientific articles are published in the areas of biomedical science, applied materials science, bioengineering, epidemiology and social science relevant to endodontic disease and its management, and to the restoration of root-treated teeth. In addition, review articles, reports of clinical cases, book reviews, summaries and abstracts of scientific meetings and news items are accepted. Please read the instructions below carefully for details on the submission of manuscripts, the journal's requirements and standards as well as information concerning the procedure after a manuscript has been accepted for publication in Giornale Italiano di Endodonzia. Giornale Italiano di Endodonzia is indexed in Scopus, Science Direct, Embase and published online by Ariesdue, Milan, Italy and hosted by PAGEPress, Pavia, Italy. All articles are available on www.giornaleitalianoendodonzia.it.

We publish, monthly, new articles in the Early View section while the full Journal is issued twice a year, in June and November.

Authors are encouraged to visit www.giornaleitalianoendodonzia.it for further information on the preparation and submission of articles and figures.

Ethical guidelines

Giornale Italiano di Endodonzia adheres to the below ethical guidelines for publication and research.

Authorship and Acknowledgements

Authors submitting a paper do so on the understanding that the manuscript has been read and approved by all authors and that all authors agree to the submission of the manuscript to the Giornale Italiano di Endodonzia. Giornale Italiano di Endodonzia adheres to the definition of authorship set up by The International Committee of Medical Journal Editors (ICMJE). According to the ICMJE, authorship criteria should be based on 1) substantial contributions to conception and design of, or acquisiation of data or analysis and interpretation of data, 2) drafting the article or revising it critically for important intellectual content and 3) final approval of the version to be published. Authors should meet conditions 1, 2 and 3. It is a requirement that all authors have been accredited as appropriate upon submission of the manuscript. Contributors who do not qualify as authors should be mentioned under Acknowledgements.

Manuscript preparation

Manuscripts should be uploaded as Word (.doc) or Rich Text Format (.rtf) files (not write-protected) plus separate figure files: TIF, EPS, JPEG files are acceptable for submission.

The text file must contain the **abstract, main text, references, tables and figure legends**, but no embedded figures or title page. The title page should be provided as a separate file. In the main text, please reference figures as for instance **figure 1, figure 2** etc to match the tag name you choose for the individual figure files uploaded.

Please note that **manuscripts must be written in English**. Authors whose native language is not English are strongly advised to have their manuscript checked by a language editing service or by a native English speaker prior to submission.

Manuscript Types Accepted

Original Scientific Articles must describe significant and original experimental observations and provide sufficient detail so that the observations can be critically evaluated and, if necessary, repeated. Original Scientific Articles must conform to the highest international standards in the field.

Systematic Review Articles reconsider and bring previously published systematic reviews up to date. This allows authors to present changes to the review while avoiding unwarranted duplication in the literature. A guiding principle for an update is that it is an event that is discrete and distinct from the conduct and reporting of the original systematic review (or previously updated review). This means that at a minimum the search for studies will have been brought up to date and that any changes to the results and conclusions of the original review (or a previously updated review) are described. Systematic review updates will not usually warrant publication of a new full-length article. However, any published update will be an independent publication. It will not be part of the original review publication (or previously updated review).

We encourage authors to be innovative in how they report and present systematic review updates. Systematic review updates are not appropriate for corrections/errata. Authors must clearly acknowledge and reference any previously-published work they are updating.

Review Articles are accepted for their broad general interest; all are refereed by experts in the field who are asked to comment on issues such as timeliness, general interest and balanced treatment of controversies, as well as on scientific accuracy. Reviews should generally include a clearly defined search strategy and take a broad view of the field rather than merely summarizing the authors´ own previous work. Extensive or unbalanced citation of the authors´ own publications is discouraged.

Mini Review Articles are accepted to address current evidence on well-defined clinical, research or methodological topics. All are refereed by experts in the field who are asked to comment on timeliness, general interest, balanced treatment of controversies, and scientific rigor. A clear research question, search strategy and balanced synthesis of the evidence is expected. Manuscripts are limited in terms of word-length and number of figures.

Clinical Articles are suited to describe significant improvements in clinical practice such as the report of a novel technique, a breakthrough in technology or practical approaches to recognised clinical challenges. They should conform to the highest scientific and clinical practice standards.

Case Reports or **Case Series** illustrating unusual and clinically relevant observations are acceptable, but they must be of sufficiently high quality to be considered worthy of publication in the Journal. On rare occasions, completed cases displaying nonobvious solutions to significant clinical challenges will be considered. Illustrative material must be of the highest quality and healing outcomes, if appropriate, should be demonstrated.

Case reports should be written using the **Preferred Reporting Items for Case reports in Endodontics (PRICE) 2020 guidelines.** A PRICE checklist and flowchart (as a Figure) should also be completed and included in the submission material. The PRICE 2020 checklist and flowchart can be downloaded from: http://pride-endodonticguidelines.org/price/. It is recommended that authors consult the following papers, which explains the rationale for the PRICE 2020 guidelines and their importance when writing manuscripts:

- Nagendrababu V, Chong BS, McCabe P, Shah PK, Priya E, Jayaraman J, Pulikkotil SJ, Setzer FC, Sunde PT, Dummer PMH. *PRICE 2020 guidelines for reporting case reports in Endodontics: a consensus-based development.* Int Endod J. 2020 Feb 23. Doi: 10.1111/iej.13285. https://onlinelibrary.wiley.com/doi/10.1111/iej.13285.
- Nagendrababu V, Chong BS, McCabe P, Shah PK, Priya E, Jayaraman J, Pulikkotil SJ, Dummer PMH. *PRICE 2020 guidelines for reporting case reports in Endodontics: Explanation and elaboration.* Int Endod J. 2020 Mar 28. Doi: 10.1111/iej.13300. https://onlinelibrary.wiley.com/doi/abs/10.1111/iej.13300.

Manuscript Format

The **official language** of the publication is **English**. It is preferred that manuscript is professionally edited. All services are paid for and arranged by the author and use of one of these services does not guarantee acceptance or preference for publication.

Authors should pay special attention to the **presentation** of their research findings or clinical reports so that they may be communicated clearly.
Technical **jargon** should be avoided as much as possible and clearly explained where its use is unavoidable. **Abbreviations** should also be kept to a minimum, particularly those that are not standard. Giornale Italiano di Endodonzia adheres to the conventions outlined in *Units, Symbols and Abbreviations: A Guide for Medical and Scientific Editors and Authors.* If abbreviations are used in the text, authors are required to write full name+abbreviation in brackets [e.g. Multiple Myeloma (MM)] the first time they are used, then only abbreviations can be written (apart from titles; in this case authors have to write always the full name).
If names of equipments or substances are mentioned in the text, brand, company names and locations (city and state) for equipment and substances should be included in parentheses within the text.
The **background** and **hypotheses** underlying the study, as well as its main conclusions, should be clearly explained.
Titles and abstracts especially should be written in language that will be readily intelligible to any scientist.

Structure
All manuscripts submitted to Giornale Italiano di Endodonzia should include Title Page, Abstract, Main Text, References, Clinical Relevance, Conflict of Interest, Acknowledgements, Tables, Figures and Figure Legends as appropriate.
Title Page should bear:
I. Title, which should be concise as well as descriptive (no more than 150 letters and spaces);
II. Initial(s) and last (family) name of each author;
III. Name and address of department, hospital or institution to which the work should be attributed;
IV. Running title (no more than 30 letters and spaces);
V. Three to five key words (in alphabetical order);
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Abstracts should be no more than 250 words giving details of what was done.

Abstract for Original Scientific Articles should be no more than 250 words giving details of what was done using the following structure.
Aim: give a clear statement of the main aim of the study and the main hypothesis tested, if any.
Methodology: describe the methods adopted including, as appropriate, the design of the study, the setting, entry requirements for subjects, use of materials, outcome measures and statistical tests.
Results: give the main results of the study, including the outcome of any statistical analysis.
Conclusions: state the primary conclusions of the study and their implications. Suggest areas for further research, if appropriate.

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Conclusion: Provide a brief summary of the limitations of the evidence included in the review (e.g. study risk of bias, inconsistency and imprecision) and a general interpretation of the results and important implications.

Abstract for Review Articles should be non-structured, no more than 250 words giving details of what was done including the literature search strategy.

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Summary: describe the methods adopted including, as appropriate, the design of the study, the setting, entry requirements for subjects, use of materials, outcome measures and analysis if any.
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Methodology: describe the methods adopted.
Results: give the main results of the study.
Conclusions: state the primary conclusions of the study.

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Conclusions should contain a summary of the findings.

Main Text of Systematic Review Articles

should be divided into Introduction, Methodology, Results, Discussion, Conclusion.
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Main Text of Review Articles

should be divided into Introduction, Review and Conclusions.
The Introduction section should be focused to place the subject matter in context and to justify the need for the review. The Review section should be divided into logical subsections in order to improve readability and enhance understanding. Search strategies must be described and the use of state-of-the-art evidence-based systematic approaches is expected. The use of tabulated and illustrative material is encouraged. The Conclusion section should reach clear conclusions and/or recommendations on the basis of the evidence presented.

Main Text of Mini Review Articles

should be divided into Introduction, Review and Conclusions; please note that the Conclusions section should present clear statements/recommendations and suggestions for further work. The manuscript, including references and figure legends, should not normally exceed 4,000 words.

Main Text of Case Reports and Case series

should be divided into Introduction, Report, Discussion and Conclusion. They should be well illustrated with clinical images, radiographs, diagrams and, where appropriate, supporting tables and graphs. However, all illustrations must be of the highest quality.

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British Endodontic Society - Guidelines for root canal treatment. Giornale Italiano di Endodonzia 1979;16:192-5.

Journal supplement
Frumin AM, Nussbaum J, Esposito M. Functional asplenia: demonstration of splenic activity by bone marrow scan (Abstract). Blood 1979;54 (Suppl. 1):26a.

Books and other monographs
Personal author(s)
Gutmann J, Harrison JW. Surgical Endodontics, 1st edn Boston, MA, USA: Blackwell Scientific Publications, 1991.

Chapter in a book
Wesselink P. Conventional rootcanal therapy III: root filling. In: Harty FJ, ed. Endodontics in Clinical Practice, (1990), 3rd edn; pp. 186-223. London, UK: Butterworth.

Published proceedings paper
DuPont B. Bone marrow transplantation in severe combined immunodeficiency with an unrelated MLC compatible donor. In: White HJ, Smith R, eds. Proceedings of the Third Annual Meeting of the International Society for Experimental Rematology; (1974), pp. 44-46. Houston, TX, USA: International Society for Experimental Hematology.

Agency publication
Ranofsky AL Surgical Operations in Short-Stay Hospitals: United States-1975 (1978). DHEW publication no. (PHS) 78-1785 (Vital and Health Statistics; Series 13; no. 34.) Hyattsville, MD, USA: National Centre for Health Statistics.

Dissertation or thesis
Saunders EM. In vitro and in vivo investigations into root-canal obturation using thermally softened gutta-percha techniques (PhD Thesis) (1988). Dundee, UK: University of Dundee.

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