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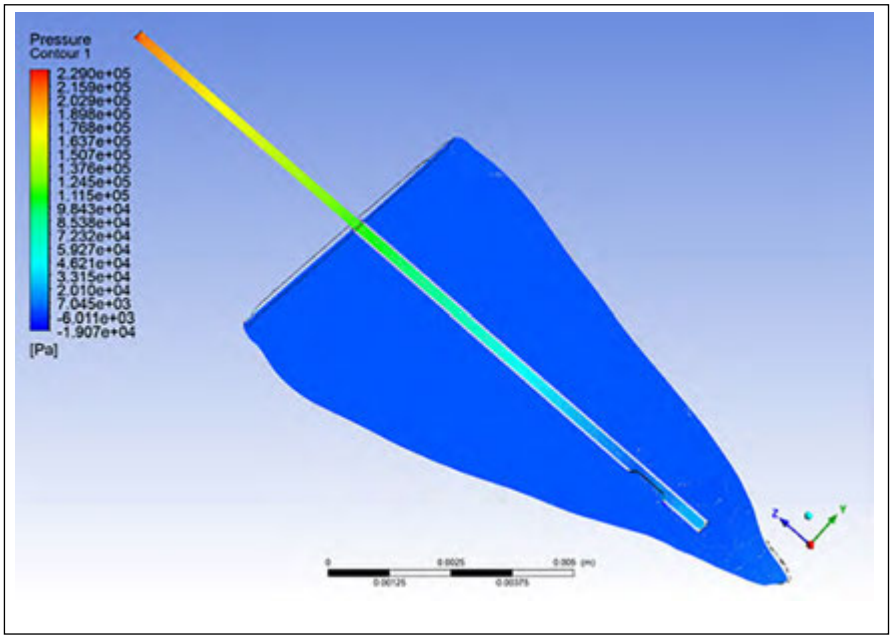

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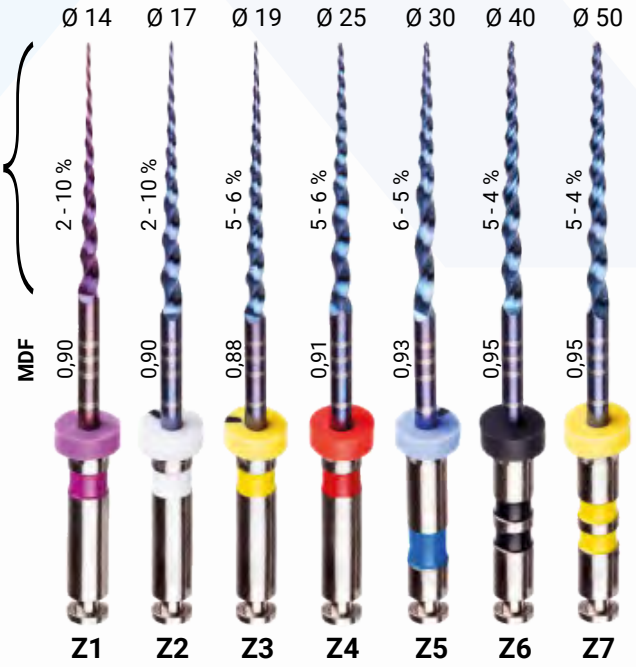

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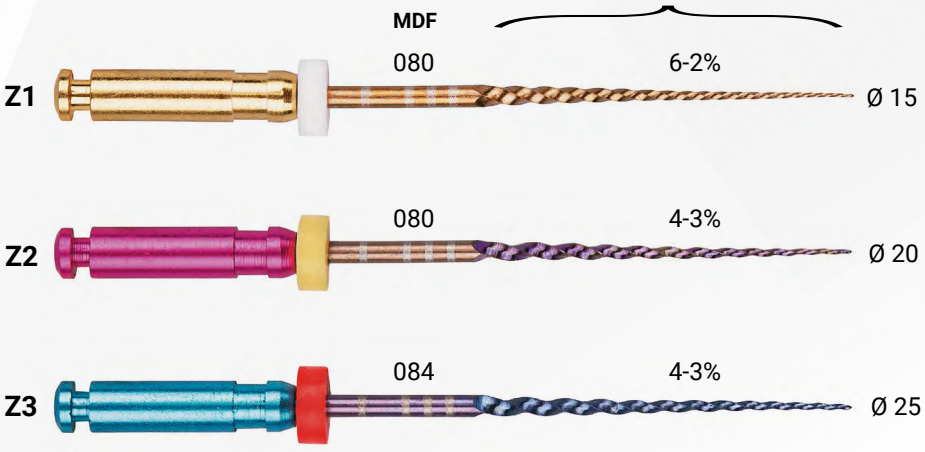

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REGISTRATION Court of Milan n° 89, 3 March 2009

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Editorial

Endodontics: the present and the future

Sandro Rengo
Editor-in-Chief
Giornale Italiano
di Endodonzia
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The IV International Congress of the Italian Society of Endodontics (SIE) will take place, as usual, in Bologna from 3 to 5 November 2022. The event entitled Endodontics: the present and the future *will be focused on future perspectives in the endodontic field considering the wide scientific and clinical progresses obtained in the present.*

Several current topics will be discussed as regenerative endodontic procedures, use of modern methods, such as CTCB and artificial intelligence, and application of new generation materials, that not only ease operative protocols but also increase the stability of clinical success over time.

The international value of the event stresses the importance of the current transitional moment through the future, not only within endodontic field, with challenges focused on the passage from traditional therapeutic approaches to application of innovative materials, methods and diagnostic tools that will change the management of both therapy and patient.

This strong predisposition to renovate can be observed even within the scientific community that is developing new research area, as patient perception and approach to therapy. The same tendency is highlighted in the present issue of Giornale Italiano di Endodonzia in which new trend topics have been studied in depth, such as the effect of endodontic therapy on physiological aspect of patients and the impact of publications dealing with endodontics on scientific community. Specifically, two papers in the present issue are represented by bibliometric analyses with the aim to analyze, through mathematical and statistical methods, the distribution models of publications and their divulgation within specific fields. In particular, evaluation of endodontic irrigation activated by laser and global impact of papers published on Giornale Italiano di Endodonzia since 1987 had been assessed.

In an increasingly moving world, science represents, without any doubt, the fundamentals for progress and a crucial starting point to move forward until the future.

Ready for a productive cultural, interpersonal and convivial exchange we are looking forward to see you at the IV International Congress of the Italian Society of Endodontics.

Peer review under responsibility of Società Italiana di Endodonzia.

10.32067/GIE.2022.36.02.13

ORIGINAL ARTICLE

Curved canal morphological changes after over instrumentation and apical foramen shaping with R-Pilot®, ProDesign Logic® and ProGlider®

ABSTRACT

Aim: *To evaluate the apical canal morphological change, centering ability, and apical transportation of curved canals after foraminal enlargement 1 mm beyond the apex with different instruments and after apical foramen shaping.*
Methodology: *Thirty-three mesiobuccal molars' canals with curvatures between 25 and 35 and a radius of less than 10 mm were selected and divided according to the instrument used 1 mm beyond the apical foramen: R-Pilot #12.5/.04(RPG), ProDesign Logic #25/.01(PDG), and ProGlider #16/.02(PGG). After over instrumentation, #25/.05 ProDesign Logic prepared the canals until the apical foramen. Micro-CT scans obtained before instrumentation (time point 1), after instruments use 1 mm beyond foramen (time point 2) and after final preparation (time point 3) were used to evaluate apical canal morphological changes according to the area, the ratio of Feret's diameters and circularity, transportation and centering. Data were analyzed by parametrical or non-parametrical tests (α=0.05).*
Results: *PDG increased the apical foramen area from time point 1 to 3 (P=0.03). There were no differences in the ratio of Feret's diameters or circularity (P>.05). In all groups, apical transportation was in mesial direction and increased after final preparation in RPG (P=0.01). Instrument centering ability was better at time point 3 than 2 in PDG (P=0.01), and PDG presented better centering than RPG at time point 3 (P=0.02).*
Conclusion: *Instruments used 1 mm beyond the apical foramen combined with #25/.05 final preparation did not lead to apical canal morphological change. ProDesign Logic #25/.01 followed by #25/.05 improved centering without increasing transportation in root canals.*

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KEYWORDS *Apical foramen, endodontics, root canal, root canal preparation*

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Introduction

Cleaning and shaping curved root canals remains a challenge during endodontic treatments. Successful treatment is linked to numerous factors, such as the correct instrumentation and debridement of the canal and the preservation of its original anatomical trajectory (1).
The ideal limit of canal therapy in teeth with vital pulp or infected canals is controversial. Extended root canal preparation techniques, by over instrumentation with or without enlarging the foramina are being investigated (2, 3, 4). This maneuver could promote a more efficient mechanical debridement and disinfection (5) apart from favoring repair, mainly in cases of apical periodontitis (6). However, one of the major concerns regarding apical foramen enlargement is the possibility of postoperative pain. Studies suggested that apical enlargement and non-enlargement techniques resulted in the same response for postoperative pain (7, 8). On the other hand, the effects of over instrumentation with NiTi rotary systems on foramen might promote morphological changes of the apical foramen, especially when curved canals are cleaned.
Reciprocating and continuous rotary systems to realize this maneuver are available, with different designs, structures, and materials manufactured using different heat treatments. ProGlider® rotary files (Dentsply/Maillefer Instruments S.A., Ballaigues, Switzerland), manufactured from M-wire, have a square cross-section, tip size 16 and taper .02 to .08. ProDesign Logic® (Easy Dental Equipment, Belo Horizonte, Brazil), also continuous rotary files, are manufactured from the CM alloy and have a helix-shaped cross-section, tip size 25, and continuous taper .01. The reciprocating systems available on the market include the M-wire R-Pilot® (VDW, Munich, Germany) files, which have an S-shaped cross-section, a tip size 12.5, and a continuous taper .04.
This study evaluated the apical canal morphological change, centering ability, and apical transportation of curved canals after foraminal enlargement 1mm beyond the apex with different instruments and after apical foramen shaping by means of micro-computed tomography images. The null hypothesis was that the use of different instruments 1 mm beyond the apical foramen and apical foramen shaping will not lead anatomical changes in the root canal.

Methodology

This study was approved by the Research Committee of the School of Dentistry of the Federal University of Rio Grande do Sul (UFRGS), Brazil, and by the Research Ethics Committee of the same institution (protocol CAAE 78641417.7.0000.5347).

Sample selection
Extracted human permanent maxillary molars with fully formed roots and no history of endodontic treatment were included in the study. Mesiobuccal root canal curvature was determined according to the degree (9) and radius (10) of canal curvature. Curvatures between 25° and 35° degrees and a radius of less than 10 mm were selected. After examination of the teeth under micro-computed tomography (Micro-CT) (time point 1), only those whose mesiobuccal canals had an apical foramen diameter of 100 to 150 µm were included (n=33).
Sample size calculation was performed in G*Power 3.1.4 (G*Power 3.1 for Macintosh; Heinrich Heine, Universität Düsseldorf, Dusseldorf, Germany), an effect size of 0.1 was estimated, and power of 80%, into a one-way ANOVA procedure.
The selected teeth were distributed randomly into three groups according to the instrument used (n=11) (Table 1). The samples were stored in distilled water during all experimental period.

Endodontic procedures
Spherical diamond tip (1012, KG Sorensen, Barueri, Brazil) accessed the cavities and Endo Z tip (Dentsply/Maillefer) completely removed the pulp chamber

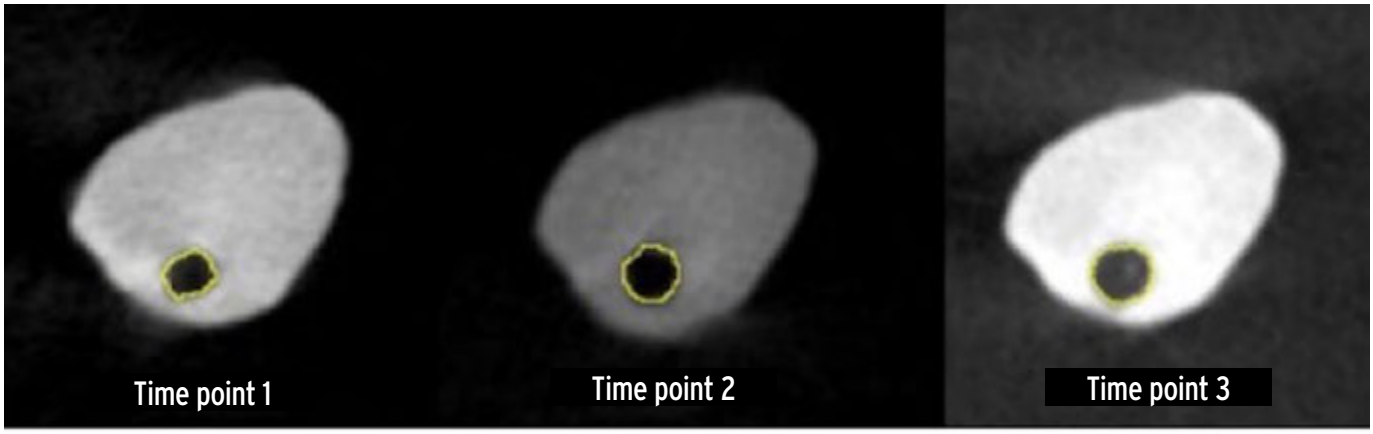

Figure 1
Images illustrating the boundary of the apical foramen anatomical changes after the use of instruments 1mm beyond foramen (time point 2) and final preparation (time point 3) in comparison with baseline images (time point 1).

roof. The mesiobuccal canals were explored using a #08 K-type file (Dentsply/Maillefer) until its tip reached the foramen. The length measured on this file was defined as the working length (WL), on the anatomical apex.
After that, the samples were randomly distributed in one of the experimental groups, according to the instrumented used to instrument the canal 1 mm beyond the WL:
-RPG: #12.5/.04 R-Pilot® in reciprocating motion;
-PDG: #25/.01 ProDesign Logic® in rotary motion at 350 rpm and torque of 1N;
-PGG: #16/.02 ProGlider® in rotary motion at 300 rpm and torque of 2N.
Next, a #25/.05 ProDesign Logic® in rotary motion at 950 rpm and torque of 4N prepared the entire length canals (WL), until the apical foramen (final preparation). All files were used in an endodontic VDW Silver engine (VDW, Munich, Germany), operated with a 16:1 contra-angle, with a slow, in-and-out pecking motion, according to the manufacturer's instructions. When the instrument reached the WL, it was removed from the canal. The same trained operator performed all endodontic procedures. Each set of files was used to prepare four canals.
At each instrument change, canals were irrigated with 2 mL of 2.5% sodium hypochlorite (Iodontosul - Industrial Odontológica do Sul LTDA, Porto Alegre, Brazil), using a conventional disposable syringe and a 29-gauge side-vented Endo-Eze irrigation needle (Ultradent, South Jordan, UT).

Micro-computed tomography (micro-CT)
Images were acquired using a SKYSCAN (Bruker Micro-CT, Kontich, Belgium) scanner at 70 kV, 100 mA, 13.3 mm FOV (XY), 7.0 mm FOV (Z) and 0.013 mm/Pix voxel size.
Teeth were scanned at three time points: 1-before instrumentation, 2-after the use of instruments 1 mm beyond foramen, and 3-after final preparation. A support model made from ExpressTM XT Putty Soft (3M ESPE, St. Paul, MN) addition silicone was used to standardize the individual positioning of each tooth for micro-CT scanning. Reconstructed axial slices (2D) were visualized using the DataViewer software (Extron, Anaheim, CA), which was used to process images for matching and cutting plane selection. The apical third was analyzed by one blinded and trained evaluator. The root canal section orthogonal to the canal axis was defined on the first apical section where the apical foramen was visible. The number used to identify the position of the selected section was the same at the three time points.

Analysis of area, ratio of Feret's diameters and circularity of the apical foramen
Image J software (National Institute of Health, Bethesda, MD) calculated area, ratio of Feret's diameters and circularity of the apical foramen at the three time points. The boundary of the apical foramen of each specimen was traced ma-

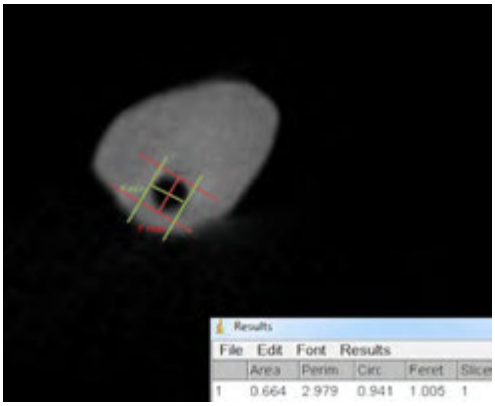

Figure 2
The maximum (Fmax) and minimum (Fmin) Feret's diameters are defined as the furthest and shortest distances, respectively, between two parallel tangents on the boundary of a shape.

nually using the Draw tool (Figure 1). The area, circularity, and Feret's diameters were calculated using the Set Measurements tool. Circularity was determined based on a perfect circle, which tends towards 1.0, in contrast with a straight line, which is 0.0. Feret's diameters were defined as the longest distance between two parallel straight lines that are tangent to the shape. Ratio of Feret's diameters was calculated as the ratio of maximum to minimum Feret's diameters (Figure 2).

Analysis of apical transportation and centering

Apical transportation and centering ability were analyzed in a linear mesiodistal direction using Adobe Photoshop software CS6 (v. 13.0x32, Adobe Systems, San Jose, CA). Transportation and centering were evaluated after instrumentation 1 mm beyond foramen, comparing the images at time points 1 and 2; and after final preparation, comparing the images at time points 2 and 3 (Figure 3). Apical transportation was calculated as follows:

(X1–X2) – (Y1–Y2)

where X1 was the shortest distance from the distal portion of the root to the periphery of the unprepared canal; X2, the shortest distance from the distal portion of the root to the periphery of the prepared canal; Y1, the shortest distance from the mesial portion of the root to the periphery of the unprepared canal; and Y2, the shortest distance from the mesial portion of the root to the periphery of the prepared canal.

A result of zero indicated no canal transportation; a positive result indicated transportation toward the distal region; and a negative result indicated transportation toward the mesial region (11).

Centering was calculated using the following formula:

(X1–X2)/(Y1–Y2) or (Y1–Y2)/(X1-X2)

The numerator of the formula was the lowest number found when the values were unequal. A value close to 1 indicated a better centering, and a value close to 0, a poorer centering (11).

Statistical analysis

The Shapiro Wilk test evaluated data normality.

Repeated-measures analysis of variance (ANOVA), followed by the Tukey test for multiple comparisons, compared the area and ratio of Feret's diameters at the three time points in the same group. One-way ANOVA compared different groups at the same time point. As circularity data did not have a normal distribution, time points in the same group were com-

Table 1
Test groups and treatment time points

Groups	n	Time point of analysis under micro-CT according to file used		
		Time point 1	Time point 2	Time point 3
R-Pilot® (RPG)	11	Without endodontic preparation	After the use of RPG	Final Preparation (#25/.05 ProDesign Logic)
ProDesign Logic® (PDG)	11	Without endodontic preparation	After the use of PDG	Final Preparation (#25/.05 ProDesign Logic)
ProGlider® (PGG)	11	Without endodontic preparation	After the use of PGG	Final Preparation (#25/.05 ProDesign Logic)

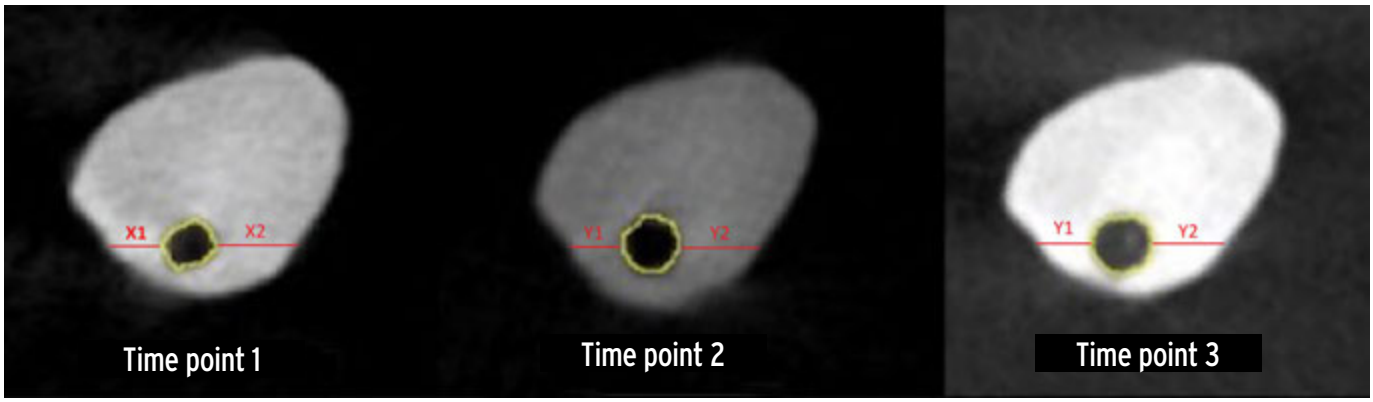

Figure 3
Time Point 1, 2 and 3 micro-CT images for determination of canal transportation and centering ratio. X1=shortest distance from the distal portion of the root to the periphery of the unprepared canal; X2= shortest distance from the distal portion of the root to the periphery of the prepared canal; Y1shortest distance from the mesial portion of the root to the periphery of the unprepared canal; and Y2=shortest distance from the mesial portion of the root to the periphery of the prepared canal.

pared using the Friedman non-parametric test, and the Kruskal-Wallis compared groups at the same time point. The data about apical transportation and centering at the same time point were compared between groups using one-way ANOVA, and data for the same group at time points 2 and 3 by dependent t test. The level of significance was set at 5% (P≤.05). GraphPad Prism 7 software (GraphPad Software Inc., San Diego, CA) performed statistical analyses.

Results

Although there was an increase in apical foramen area from time point 1 to 3 in all groups, this increase was significant only in PDG from time point 1 (before preparation) to time point 3 (after final preparation) (P=0.03). Apical foramen ratio of Feret's diameters and circularity were similar at the three time points for all groups (P>.05). The comparison of foramen area, ratio of Feret's diameters and circularity between groups at the same time point revealed no significant differences (P>.05) (Table 2).
Table 3 shows data about apical transportation and centering. There was a tendency to transportation in the mesial direction of the canal after over instrumentation and final preparation in all groups. There were no significant differences between groups at the same time point (P>.05), and transportation increased

Table 2

Mean and standard deviation (±) of root canal area (mm²), ratio of Feret's diameters (mm/mm) and median value (maximum value; minimum value) of canal circularity (mm²/mm²) in the test groups at time points 1 (no preparation), 2 (after the use of instruments 1mm beyond foramen) and 3 (after final preparation) (p>0.05)

		RPG	PDG	PGG
Area	Time point 1	0.52 ± 0.37	0.46 ± 0.24[a]	0.51 ± 0.29
	Time point 2	0.71 ± 0.31	0.66 ± 0.26[ab]	0.63 ± 0.36
	Time point 3	0.92 ± 0.39	0.83 ± 0.26[b]	0.81 ± 0.27
Ratio of Feret's diameters	Time point 1	0.51 ± 0.29	0.72 ± 0.16	1.19 ± 0.44
	Time point 2	0.63 ± 0.36	0.75 ± 0.14	1.23 ± 0.45
	Time point 3	0.81 ± 0.27	0.78 ± 0.12	1.31 ± 0.38
Circularity	Time point 1	0.82 (0.93; 0.44)	0.84 (0.94; 0.43)	0.74 (0.90; 0.53)
	Time point 2	0.82 (0.93; 0.47)	0.88 (0.94; 0.52)	0.74 (0.92; 0.54)
	Time point 3	0.85 (0.93; 0.51)	0.87 (0.98; 0.47)	0.78 (0.93; 0.57)

**Different lowercase letters indicate significant differences in the same column (P<.05)*

Table 3

Mean and standard deviation (±) of apical transportation (mm) and centering (mm) in the test groups after the use of instruments 1 mm beyond foramen (time point 2) and final preparation (time point 3)

		RPG	PDG	PGG	P value
Apical transportation	Time point 2	-0.27^{a} ± 0.18	-0.57^{a} ± 0.36	-0.25^{a} ± 0.27	
	Time point 3	-0.89^{b} ± 0.61	-0.44^{a} ± 0.31	-1.04^{b} ± 1.04	
P value		0.01			
Centering ability	Time point 2	0.27^{a} ± 0.33	0.05^{a} ± 0.17	0.25^{a} ± 0.24	
	Time point 3	0.10^{aA} ± 0.15	0.52^{bB} ± 0.34	0.22^{aAB} ± 0.22	0.02
P value			0.01		

**Different lowercase letters indicate significant differences in the same column (P<.05)*
**Different uppercase letters indicate significant differences in the same line (P<.05)*

significantly after final preparation in RPG (P=0.01). Instrument centering ability was significantly better at time point 3 than at time point 2 in PDG (P=0.01), and PDG presented significantly better centering than RPG at the time point 3 (P=0.02).

Discussion

Preserve the original shape of the canal after instrumentation is associated with better endodontic treatment results (1). This study analyzed the shaping ability of three types instruments used for instrumentation 1 mm beyond the apical foramen followed by final preparation to entire canal length, that is, to the apical foramen, using a #25/.05 rotary file. There was an increase in apical foramen area in PDG from time point 1 to 3, the transportation increased significantly after final preparation in RPG and PGG, and PDG improved centering ability after final preparation, rejecting the null hypothesis. The use of a file with a caliber smaller than that of the apical foramen may not clean the canal efficiently. Correct foraminal enlargement is achieved using larger instruments. When the canal is instrumented past the apical foramen, there is a better bacterial removal, which promotes healing (5). Foraminal enlargement creates conditions for the growth of connective tissue in the space of the unfilled apical portion during the repair process (12). However, enlargement may promote apical morphological changes, especially in curved canals, and lead to unsatisfactory filling (13). The present study showed that even with foraminal enlargement in all groups, the foramen circularity was maintained.

Each instrument analyzed has a distinct cross-section, taper and tip diameter. ProDesign Logic® has a double helix cross-section, tip #25 and taper .01 (14); ProGlider® has a square cross-section, #16 tip and a variable taper, beginning at .02 in the first millimeter (15); and, R-Pilot® has an S-shaped cross-section, #12.5 tip and taper .04 (16). Therefore, as we performed an overlap of 1 mm during root canal preparation, the resulting foraminal diameter when using ProDesign Logic®, ProGlider® and R-Pilot® were #18, #16.5 and #26, respectively.

Regarding apical enlargement, R-Pilot®, ProDesign Logic®, and ProGlider® did not changed the circularity and ratio of Feret's diameters after use, thus preserved the foramen anatomical features. After final preparation using #25/.05 file, few changes from circular to oval shape were observed in all groups, although they had increased the foraminal surface area. Similar results were observed using Reciproc Blue R25 in the apical foramen and beyond the apex (17), and using Reciproc Blue R25 and XP-endo Shaper at the apical foramen limit (18).

The foramen ovalization has been reported following canal over instrumentation. The major foramen was photographed before and after over instrumentation with Pro-

Taper Universal and ProFile Vortex, resulting in changes in the original position of the foramen (4). Using a digital microscope for analyses, foramen deformation was observed after using Reciproc (#25/.08), WaveOne (#25/.08), and ProDesign R (#25/.06) in two different working lengths, 0.00 mm and 1.0 mm beyond the foramen (3). Even, after the use of #25/.08 files, 1 mm beyond the foramen (19). Our results may be correlated with prior instrumentation with small diameter and taper instruments 1 mm beyond the foramen.

As previously observed, the analysis of canal transportation revealed that all tested files led to transportation towards the external (mesial) wall in the apical third (4, 20). Transportation in this direction might be explained by the fact that the distal wall pushes the file, particularly if the file has a larger taper, in a direction against the mesial wall, opposed to the curvature (21). Despite the absence of significant differences between groups, apical transportation was significantly greater in RPG after final preparation (time point 3). In PDG, however, transportation did not change significantly after the final preparation, which may be associated with the fact that the #25.05 ProDesign Logic® worked with a free tip at the apical foramen during final preparation. However, apical transportation becomes clinically relevant when it exceeds 300 µm (22), which occurred in all groups after final preparation. It also were observed in PDG after the over instrumentation, which may be explained by the fact that the tip diameter of the #25.01 ProDesign Logic® files is greater than that of the other two tested instruments.

At time point 3, PDG showed better centering ability than RPG. Also in PDG canal centering was significantly better after final preparation than after over instrumentation. As previously mentioned, at PDG the apical foramen was enlarged during the use of #25/.01 ProDesign Logic®, leaving the #25/.05 ProDesign Logic® tip work freely during final preparation, which might have contributed to our results.

However, the preservation of the original anatomical path decreases with increasing apical preparation, in this sense, the apical preparation was limited to the size 25 file in the present study, which may be a limitation of the study.

As in previous studies, the curvature degree of the mesiobuccal roots ranged from 25 to 35, and their radius was shorter than 10 mm (9, 10). These curvature degrees may be at a greater risk of canal transportation (21). Moreover, selecting only canals with apical foramen diameter measuring from 150 µm to 200 µm ensured that at least one of the used files would touch the foramen.

Axial sections of the canal apical third were selected for the analyses because this region is the most critical for endodontic treatment. Correct cleaning and shaping of this region are directly associated with treatment success (1). Procedural accidents, such as apical transportation, may prevent the removal of microorganisms and organic tissue from the dentin walls, compromising the disinfection and sealing of the canal system (23). Apical transportation and centering were analyzed using micro-CT images, which ensured good precision, validity, and data reproducibility (15, 24). Other methods of analysis, such as serial cuts, clearing, and scanning electron microscopy, result in structural changes. Such changes would preclude the analysis of transportation and centering at the three time points performed herein. Apical transportation was evaluated only on the mesiodistal axial sections, as the canal along this direction is narrower than in the buccopalatal direction (25).

Despite the in vitro study limitations, the present results highlighted that the combined use of R-Pilot®, ProDesign Logic®, or ProGlider® 1mm beyond apical foramen with #25/.05 final preparation until the apical foramen did not lead apical morphological changes. ProDesign Logic® followed by a final preparation improved canal centering without increasing canal transportation.

Clinical Relevance

The use of small caliber files beyond the apical foramen combined with final prepa-

ration until the apical foramen did not impair canal shaping.

Conflict of Interest

The authors declare that they have no conflict of interest.

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ORIGINAL ARTICLE

Sociodemographic, clinical and psychological predictors of subjective avoidance in endodontic therapy

ABSTRACT

Aim: *Despite improvements in dentistry, patient's avoidance rates to dental treatments remain high. This study aimed to assess sociodemographic, clinical and psychological predictors of subjective avoidance in endodontic therapy.*
Methodology: *One hundred patients diagnosed with any type of pulp or periapical pathology that required non-surgical endodontic therapy were treated in two different clinical settings. Data were collected at two time points: a) at baseline in the waiting room before starting endodontic therapy; b) from the beginning endodontic therapy until the treated tooth regained complete functionality (a range of one to three months).*
Results: *There was a significant positive association between subjective avoidance and behavioral avoidance (t=2.248, p=.027). Women obtained significantly (t=-2.039, p=.044) higher scores in subjective avoidance (mean=5.73, SD=3.26) than men (mean=4.43, SD=3.04). Patients who have been taking medication presented significantly (t=-2.071, p=.043) higher avoidance (mean=6.25; SD=2.70) than patients who reported not needing medication (mean=4.91, SD=3.31). Bivariate analyses suggest that subjective avoidance maintained strong positive correlations with trait anxiety (p=.039), state anxiety (p=.031), dental anxiety (p<.001), dental phobia (p=.003) and phobic stimuli in dental context (p<.001).*
Conclusions: *Within the limitations of the present study, it can be concluded that the only predictor variable for avoidance is dental anxiety (p<.001).*

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Introduction

The average number of times dentists are consulted is far lower than medical doctors (Healthcare activities statistics, https://ec.europa.eu/eurostat). The importance of understanding attendance patterns, along with the barriers to dental attendance of adults, is important for the maintenance of adequate oral health among the population. Attendance rates for dental care show wide variability among EU Member States; in 2018, the Netherlands registered 2.8 consultations of a dentist on average per year, whilst at the opposite end were countries such as Romania, Cyprus and Denmark where each person consulted a dentist on average 0.5 times per year or less (Statistics-Eurostat-European Union, https://ec.europa.eu/eurostat). Particularly in Spain, the European Health Survey (EHSS) (European Survey of Health in Spain, https://www.ine.es) published in 2021 stated that 49.1% of the Spanish population had not attended an annual check-up at a dentist, 2% of the adult populations over 15 years of age had never visited a dentist and only 9% attended when they were having trouble or dental pain. In spite of this data, the Spanish Dental Council promotes healthcare with free annual check-ups and recommends that dental appointments should take place every year, and more often in the case of adults with specific dental problems (Consejo General de Dentistas de España. Información para el ciudadano y el profesional de la Odontología, https://www.consejodentistas.es). Oral health has become increasingly important as a public health monitoring measure. Patients who visit the dentist for regular dental examinations show better oral health-related attitudes and behaviours, whilst also receiving better dental treatment compared to adults who attend only when experiencing pain or having trouble (1-5). In recent years, there has been an increasing interest in patient-centered care and the individualization of treatment. However, the level of dental avoidance hasn´t decreased. Thus, in order to provide the best level of care, it is necessary to identify the variables that may influence in this situation. Armfield and Heaton (4), in their study among dentally fearful adults, concluded that there were no statistically significant differences between avoiders and non-avoiders regarding age, gender, insurance status or education (6). Nevertheless, other studies have found that based on gender, women are more likely than men to have consulted a dentist, meanwhile, regarding age, older people are less likely to visit a dentist (7). Thus, previous studies have been unsuccessful in creating a sociodemographic profile of patients who avoid.

In recent years, studies have focused on which variables are barriers to dental attendance. Based on these variables, Gragoll et al. (8) developed a typology of patients who avoid visiting dentist. The European Statistics of Income and Living Condition (Health variables of EU-SILC, https://ec.europa.eu/eurostat) Survey observed that some of the main barriers for dental attendance were cost of treatment, lack of time, travel distance to a dental provider, not knowing any good doctors or fear of doctors. Dental fear is one of the psychological variables that has aroused the most interest in previous studies (2, 4, 6, 9-11). Dental fear is a concern to both patients and dentists, as it is associated with avoidance of general dental appointments, ranging from 5.5% to 15.5% (5, 12, 13). Oosterink, De Jongh, Hoogstraten (14) reported that out of the various dental procedures, patients were most fearful of endodontic treatment. This may be because 9% of the adult population only visited dentists when they already had pain, therefore making the necessary treatments more complex. In addition, previous studies have shown that dental pain is another of the most important barriers to patients accessing dental care (2, 15-17). Although, the relationship between dental fear and dental pain is widely known, little research has

focused on the study of these two variables and their interaction with dental avoidance. In particular, it would be interesting to study both variables among patients who require more complex treatments, such as root canal treatment, due to the fact that this type of treatment is usually necessary among people who haven't maintained their regular dental check-ups. To the best of our knowledge, there are no previous studies that have included sociodemographic, clinical and psychological predictors of avoidance in a single study.
Regarding psychological variables, dental fear has been the most studied in previous studies. However, other variables that have proven to be relevant in other areas of dentistry such as self-efficacy (18-20), patient's general anxiety (21) and affectivity (22) have hardly been studied in the previous literature in relation to avoidance. In this context, and given the lack of research in this regard, the aim of this study has been to identify variables, including sociodemographic, clinical and psychological ones, that were relevant in patients' subjective avoidance when they are exposed to root canal therapy. In addition, the association between patient´s subjective avoidance and behavioral avoidance, as an objective measure, was assessed.

Methodology

Design and study sample
This longitudinal observational study was conducted in two different clinical settings. Of the 100 participants, 59 were treated at the university dental clinic, at the Health Sciences Faculty of Rey Juan Carlos University (Madrid, Spain) and 41 were treated in a private dental practice (Ferrus and Bratos Dental Practice, Madrid, Spain). Consecutive patients diagnosed with a pulp or periapical pathology that required non-surgical endodontic therapy were invited to participate in the present study, before commencing treatment. A researcher belonging to the team, who did not participate in treating the patients, was responsible for inviting them to participate. All the volunteers who were asked to participate in the study accepted to take part. Once consent had been given, in the waiting room before starting endodontic therapy, they all signed informed consent forms. The inclusion criteria were to be ≥18yr of age and to require a non-surgical endodontic treatment plan. The exclusion criteria were having a diagnosis of a severe mental disorder and/or not signing both informed consent forms (one for the study and another specific form for the treatment). This study was undertaken with the approval of the Committee for Ethics in Research of the University Rey Juan Carlos (Reg. no. 26/2014). The study was open from February 2014 to March 2019.

Procedure
Root canal treatments were performed following the recommendations of the European Society of Endodontology (Quality guidelines for endodontic treatment: consensus report of the European Society of Endodontology: https://www.e-s-e.eu). Following local anesthesia, teeth were isolated using a rubber dam and an access cavity preparation was made with a diamond bur high speed size 014 (Komet®, Lemgo, Germany). Shaping was carried out with a combination of with hand (k-files, Denstply Maillefer®, Baillagues, Switzerland) and rotary files (Protaper Universal files, Denstply Maillefer®, Baillagues, Switzerland). The chemomechanical protocol was carried out using 5.25% sodium hypochlorite between each file used. A final rinse of 18% EDTA (Ultradent®, St Louis, MO, USA) during 1 minute was used. Finally, canals were dried using paper points and obturated, using AH Plus (Denstply Sirona®, Baillagues, Switzerland) and gutta-percha using a continuous wave down pack technique of obturation (System B, SybronEndo®, Glendora, CA, USA). All treatments were carried out by a single experienced endodontist (MSc Endodontics).
Data were collected at two times points: a) at baseline in the waiting room before starting endodontic therapy (baseline measurements); b) from beginning of

endodontic therapy until the treated tooth regained complete functionality (follow-up measurements).

a) Baseline measurements

>Sociodemographic variables: age and gender were obtained from patients´ clinical history.

>Clinical variables

1) American Society of Anesthesiologist's Physical Status Classification System (ASA-PS).

The ASA-PS was developed to offer clinicians a simple categorization of the overall health status of patients. It is a grading system adopted worldwide in healthcare-related environments. The ASA-PS originated in 1941 although afterwards it has undergone several modifications (23-25). (American Society of Anesthesiologists: Guidelines, Statements, Clinical Resources, https://www.asahq.org/standards-and-guidelines).

The score consists of six classes (I to VI). In the present study, we only used class I (normal healthy patient), class II (patient with mild systemic disease) and class III (patient with severe systemic disease). Despite being routinely used, the rating denotes low inter-rater reliability with a strong reliance on work experience (26).

2) Medication: it was recorded if patients had been taking medication before the beginning of endodontic therapy in relation to their current dental problem. In addition, among the patients who did, we registered the type of medication (antibiotics and/or anti-inflammatory drugs).

3) Tooth type and endodontic variables: it was recorded if the treated tooth was a molar, premolar, incisor or canine. Pulpal status was diagnosed with clinical symptoms (palpation, percussion and thermal sensibility using a cold sensibility test). According to these symptoms, the sample was classified as irreversible pulpitis, necrosis, apical periodontitis and need for retreatment. Also, a preoperative periapical radiography of the tooth to be treated was taken in order to register if the tooth showed a radiolucent apical lesion.

>Psychological variables

1) Subjective avoidance: an ad hoc item was used to measure this variable: "To what extent would you avoid this situation?" The measure uses a 10-point Likert scale from "0=no avoidance" to "10=maximum avoidance". The higher the score obtained the higher the level of the patient´s subjective avoidance.

2) The Index of Dental Anxiety and Fear (IDAF-4C+): the IDAF-4C+ was developed by Armfield (27). It is composed of three modules: the Anxiety and Fear module (IDAF-4C), the Phobia module (IDAF-P) and the Stimulus module (IDAF-S). The anxiety and fear module, also called the four components module (IDAF-4C), is the core module. It contains eight measurements enveloping central features of dental anxiety and fear. Each component includes two items. The response formats included a 5-point Likert scale. Mean full scale scores were categorized to indicate no or little dental fear (1-1.5), low dental fear (1.51-2.5), moderate dental fear (2.51-3.5), and high dental fear (>3.5). The IDAF-4C has high internal consistency (Cronbach´s alpha=0.91) and good test-retest reliability (r=0.82) (28-29). In the present study, the internal consistency of this module was also high (Cronbach´s alpha=0.87). The phobia module (IDAF-P) is composed of five items. The first three items are used for the diagnosis of specific phobia towards dentists, as described by the American Psychiatric Association (DSM-5-TR, https://psychiatry.org). The two other items aim to provide a differential diagnosis from panic disorder and social phobia. The response options are yes/no. The IDAF-P showed good internal consistency in the present study (Cronbach´s alpha=0.64). The stimulus module (IDAF-S) comprises ten items referring to a range of anxious stimuli that could be present in the dental setting. The response format is a 5-point Likert scale. All items are analysed individually, the calculation of an overall score is not required. This module showed high internal consistency in the present study (Cronbach´s alpha=0.89).

3) Self-Efficacy: the Spanish version of the 'General Self-efficacy Scale' was used to assess self-efficacy (30). This scale is composed of 10-items such as ´If I am in trou-

ble, I can usually think of a solution´ or ´I can usually handle whatever comes my way´. The scale is a brief and widely used instrument to explain and predict human characteristics in different domains, including health behaviours. The scale is scored on a 4-point Likert-type, with a range of total scores from 10 to 40. The higher the score obtained on the scale, the higher the level of patient's self-efficacy. The General Self-efficacy scale has showed a high level of internal consistency (Cronbach´s alpha=0.83) (31). In the present study, the Cronbach´s alpha value was also 0.83.

4) Positive Affect and Negative Affect: the Spanish version of the Positive and Negative Affect Scale (PANAS) was used (32). The scale was development by Watson, Clark, Tellegen (33). This scale comprises two 10-item subscales which measure positive affect and negative affect. The items consist of single-term descriptors of affective states and are presented to the participants in random order. Examples of descriptors for positive items are ´interested´, ´alert´, and ´strong´ while descriptors for negative items are ´guilty´, ´irritable´, and ´hostile´. Each item in the subscales is scored on a 5-point Likert scale. It is a standardized measure of changes in a person's mood. The Cronbach´s alpha has indicated excellent internal consistency for both factors (0.90 and 0.91, respectively) (34-35). In the present study, the Cronbach´s alpha value was 0.85 for positive affect and 0.89 for negative affect.

5) State Trait Anxiety Inventory (STAI): in order to assess anxiety we employed the Spanish version of the State Trait Anxiety Inventory (STAI) questionnaire (36-37). This validated instrument for the measurement of anxiety consists of two scales: Trait-STAI, to measure basal anxiety, and State-STAI, to measure anxiety at a given moment; on both scales the higher the score the higher the level of anxiety (range from 0 to 60 points). The questionnaire has a good internal consistency in the Spanish adaptation, between 0.90 and 0.93 in anxiety/state and between 0.84 and 0.87 in anxiety/trait (38). In this study, the value of Cronbach´s alpha was high for both factors (0.88 for Trait-STAI and 0.87 for State-Anxiety).

b) Follow-up measurements

>Clinical variables

1) Number of canals of treated teeth

2) The Endodontic Case Difficulty Assessment Form according to the American Association of Endodontics, AAE (https://www.aae.org): this assessment form identifies three categories of considerations which may affect treatment complexity. The first category to take into account is the patient´s considerations in relation to treatment, recording anesthesia problems, patient´s ability to open mouth or presence of patient´s gag reflex, among others. The second category is in relation to the diagnosis and treatment considerations. It records, for example, the difficulty in taking x-rays or position of the tooth in the arch. The last category includes three items: trauma history, endodontic treatment history, and periodontal-endodontic condition. Based on all these considerations, treatment is classified into minimal difficulty, moderate difficulty and high difficulty.

>Delayed appointments: this behavioural indicator was registered when a restoration appointment was completed and the treated tooth had regained full functionality. The clinician registered if the patient had delayed any dental appointment necessary for the tooth to be fully restored to functionality. Delayed appointments became a dichotomous variable coding 0 (patient hasn´t delayed any appointments) or 1 (patient has delayed at least one appointment).

Statistical analysis

Data were entered into a database prepared with Statistical Program for Social Sciences (SPSS™, IBM Inc., Armonk NY Version 22.0). Analyses were conducted using SPSS. Nominal data were summarised as counts and frequencies while quantitative data were summarised as means and standard deviations. Cronbach's alpha was calculated as a reliability coefficient. Comparisons between groups were conducted with Student's t-tests or one-way ANOVA (Sheffé post-hoc comparisons). Bivariate

correlations were evaluated using Pearson correlation analyses. Predictors of subjective avoidance were evaluated with multiple linear regression (enter method). P was set at 0.05 (two-tailed). Effect sizes for significant findings were also reported.

Results

Demographic and clinical characteristics of patients. Of the 100 patients in the sample 60 percent were female (*n*=60) and 40 percent were male (*n*=40), ranged in age from 18 to 72 (mean, 42.91 years ± SD=11.92).

Table 1
Clinical characteristics of patients

Variables related to health status					
American Society of Anesthesiologists (ASA) classification	n	n	n		
	Class I	Class II	Class III		
	84	9	6		
Dental variables					
Previous medication	Yes (n)	No (n)			
	28	72			
Type of previous medication	None	Antibiotic	Anti-inflammatory	Antibiotic & Anti-inflammatory	
	72	9	13	6	
Endodontics variables					
American Association of Endodontists (AAE) Endodontic Case Difficulty Assessment Form	Minimal Difficulty	Moderate Difficulty	High Difficulty		
	33	53	14		
Tooth type	Molars	Premolars	Canines	Incisors	
	46	29	7	17	
Number of canals	1 Canal (n)	2 Canals (n)	3 Canals (n)	4 Canals (n)	
	40	15	31	14	
Pulpal diagnosis	Irreversible pulp	Pulp necrosis	Apical Periodontitis	Retreatment	
	28	36	5	31	
Radiolucent apical image	Yes (n)	No (n)			
	50	50			

Data expressed in n (equivalent to percentages given that the total sample is 100).

Table 2
Relationship between subjective avoidance and behavioural indicators of avoidance

	Behavioral avoidance				
	Yes (n=7)	No (n=93)			
	Mean (SD)	Mean (SD)	t	p	Eta^{2}p
Subjetive avoidance	7.85 (1.67)	5.09 (3.20)	2.248	.027	.53

The main clinical characteristics measured in the sample are shown in Table 1.

Subjective avoidance. Relationship with behavioural indicators of avoidance

The mean value of subjective avoidance was 5.20 (SD=3.22), ranging from 0 to 10 and mode was 5 (25%). With regards to the behavioural indicators of avoidance (delayed treatment), seven per cent of the sample delayed their treatment without giving an explanation. The range of delayed appointments was 1 to 5. The results of the analysis of the relationship between the subjective perception of avoidance and behavioural avoidance are shown in Table 2. There was a significant association between subjective avoidance and behavioural avoidance as subjective avoidance scores were significantly higher in patients who cancelled appointments compared to those who didn´t.

Sociodemographic predictors

The bivariate analyses, when age and gender were considered as sociodemographic variables, showed significant relationships in the case of gender (t=-2.039, p=.044). In particular, women obtained higher scores in subjective avoidance (mean=5.73, SD=3.26) than men (mean=4.43, SD=3.04). The value of eta partial squared was .72. No significant relationships were observed between age and subjective avoidance (r=-.143, p=.15).

Clinical predictors

The following variables were considered as clinical predictors: medication prior to the appointment in relation to the dental problem, type of medication, ASA-PS Classification System, treated tooth, number of canals in the affected tooth, pulp status, presence of a radiolucent apical lesion on the diagnostic X-ray and the degree of difficulty of the treatment according to American Association of Endodontists (AAE). The previous analyses at the bivariate level only showed statistically significant differences in relation to medication prior to the appointment as part of the dental problem (t=-2.071, p=.043). Specifically, patients who attended treatment having taken previous medication due to their dental problem (n= 28) presented significantly higher avoidance (mean= 6.25; SD= 2.70) than those patients who reported not needing medication (n=71) (mean =4.91, SD=3.31). The value of eta partial squared was .72.

Psychological predictors

As psychological predictors we included state anxiety, trait anxiety, positive affect, negative affect, dental anxiety, dental phobia, phobic stimuli and self-efficacy. Table 3 shows the Pearson correlations between subjective avoidance and psychological variables. The bivariate analyses demonstrated that subjective avoidance maintains a strong positive correlation with trait anxiety (p=.039), state anxiety (p=.031), dental anxiety (p<.001), dental phobia (p=.003) and phobic stimuli in a dental context (p<.001).

Regression analysis

Table 4 shows the results of the regression analysis, including the statistically significant sociodemographic, clinical and psychological variables in the bivariate analyses. The table shows the variables included and excluded in the model. The final model explained 18% of the variance (F=20.960; p<.001). The only predictive variable of the model (DV: subjective avoidance) was dental anxiety (p<.001).

Discussion

The present study was conducted on patients who needed root canal therapy, and

Table 3
Bivariate correlations between variables

	Mean (SD)	2	3	4	5	6	7	8	9
1. Subjetive avoidance	5.20 (3.22)	.21*	.21*	-.13	.13	.41**	.29**	.38**	.05
2. Trait anxiety	16.57 (8.77)		.78**	-.53**	.71**	.38**	.40**	.36**	-.27**
3. State anxiety	17.70 (8.22)			-.51**	.63**	.39**	.47**	.39**	-.21*
4. Positive affect	35.72 (5.09)				-.37**	-.26**	-.26**	-.31**	.29**
5. Negative affect	17.78 (6.16)					.29**	.29**	.35**	-.07
6. Dental anxiety	1.70 (.78)						.72**	.72**	-.13
7. Dental phobia	.44 (.87)							.53**	-.13
8. Phobic stimuli	2.14 (.82)								-.06
9. Self-efficacy	32 (6.86)								

*p<.05, ** p<.01

who were followed-up until complete functionality of the treated tooth. Usually, patients require this type of treatment when preventive treatments have not been carried out due to years of inadequate or missing dental routines (4,6,39-41). One of the main reasons for the lack of preventive treatments is dental fear. Specifically, one of the main dimensions of dental fear, namely ´fear of invasive treatment or pain´, has been found to be significantly associated to root canal therapy (42). In this same line, endodontic therapy has been shown to be one of the dental treatments with the highest rates of avoidance (15,42) therefore being of special interest to study further the predictors of avoidance of this type of treatment in particular. The findings of the present study showed a significant association between subjective and behavioural avoidance in patients who needed root canal therapy.

The novelty of the present study has been that subjective avoidance was measured as an independent variable of other related (but not equivalent) variables, such as dental fear. To the best of our knowledge, previous studies have registered patient´s avoidance regarding dental treatments using other indicators, frequently dental fear. Lin, et al. (10) measured intentional (subjective) avoidance associated with dental fear comparing patients who had and had not experienced root canal therapy. Similarly, Nermo, Willumsen, Johnsen (42) registered avoidance directly associated with dental fear, by asking patients if they had missed a dental appointment due to fear. In addition to subjective avoidance,

Table 4
Variables included and excluded from the regression analysis

Included variables	Beta	t	p
Dental anxiety	.422	4.578	<.001
Excluded variables			
Sex	.099	1.055	.294
Previous medication	.131	1.416	.160
Trait anxiety	.077	.777	.439
State Anxiety	.077	.766	.445
Dental phobia	-.047	-.355	.723
Phobic stimuli	.228	1.716	.089

VD: Subjetive avoidance

behavioural avoidance was also recorded in the present study. To the best of our knowledge, there are no studies that have examined the associations between subjective avoidance and behavioural avoidance. Regarding the latter, the percentages obtained in our study are in accordance with general data regarding dentist avoidance, that have shown that 9% of the general population only seeks dental assistance when they were having trouble or are in dental pain (Instituto Nacional de Estadística, https://www.ine.es).

Regarding study design and data collection, the present study was of an observational longitudinal nature, carried out in a sample of adult population while in treatment. The majority of previous studies have been cross-sectional where patients filled a questionnaire at the beginning of their visit to the dental clinic (9, 43-44) although other studies have observed patients over years in order to assess the evolution of psychological factors (42, 45). In our opinion, it has been of interest to register subjects at a time when they needed endodontic therapy and to have continued their follow-up until full function of the tooth was recovered, especially to measure avoidance.

According to our results, certain sociodemographic variables could predict subjective dental avoidance. With regards to gender, the results of previous research have not always been consistent, as some authors have found that men are more prone to avoidance whereas others have not found any differences between genders (7,46-48). In our study, women showed more avoidance, this could be explained by the use of a specific ad-hoc item to evaluate subjective avoidance. Our results suggest that age is not a predictor for subjective avoidance, which is in accordance with previous literature (6,48). Even though dental care attendance rates indicated a slight variability among EU Member States suggesting that elderly people tended to visit dentists less often than younger people (Healthcare activities statistics, https://ec.europa.eu/eurostat). In our study only 7% of the participants were older than 65, which could explain the absence of significant avoidance-age relationships. Regarding the clinical variables considered, none of them have shown a significant relationship with dental subjetive avoidance. This is the first study, to the best of our knowledge, that encompasses specific endodontic variables in relation to treatment avoidance. Previous studies have analized its role on the evolution of pain in endodontic therapy (49-52) or regarding seeking dental assistance due to pain (10, 16, 47, 53-54).

One of the findings of interest in our study has been that subjetive avoidance was significantly higher in patients who had taken previous medication compared to patients who hadn´t taken it. To our knowledge, no previous studies in the endodontic field have reported whether patients had been taken medication prior to endodontic therapy due to their dental problem. Patients´ need for medication to relieve their sysmtoms could be interpreted as an objective measure of the need for dental treatment in patients, although pain thresholds vary greatly from one patient to another. The results found in the current study could be interpreted if we hypothesize that the patients who took medication delayed visiting the dentist even more as the medication mitigated their symptoms. Our results are in agreement with Falcon, et al. (55) who found that patients who receive palliative care are highly associated with incomplete nonsurgical endodontic treatment. A possible explanation of this is that patients with high rates of dental avoidance, relieved their symptoms with medication. When the medication stopped working for them, they sought a dentist for an emergency appointment. Dentists are able to relieve acute pain but need longer appointments to complete root canal treatment and often a second appointment to restore the complete functionality of the tooth. Again, this could increase avoidance rates as patients will have relieved their symptoms and therefore won´t return for further appointments. On the other hand, our results suggest that this is in line with the general models proposed to explain treatment adherence. In them, the perception of the symptoms

on behalf of the patient is considered a main predictor of adherence to treatment (56-57). The gap between knowledge creation and implementation remains wide with few studies documenting the iterative process of comprehensive implementation in clinical settings. The objective of this study was to improve adherent physical therapy care according to CPG's for low back pain and describe the knowledge to action (K2A Our study has highlighted that patients who have taken medication prior to appointments reduced their acute symptoms and decreased adherence to treatment, which in turn produced greater rates of patient treatment avoidance. As a consequence, patients experienced poorer oral health quality-of-life and poorer perceived oral health (58-60), in turn contributing to an increase in the cost of general health service (6).

Regarding psychological predictors, the results of the present study suggest that self-efficacy and negative affect don't show any correlations regarding subjetive avoidance. In relation to negative affect in dentistry, no previous studies were found associating it to avoidance. However, neuroticism as a construct has been closely linked to negative affect (61), defined as a trait disposition to experience negative affect, including anger, anxiety, self-consciousness, irritability, emotional instability, and depression (62). In dentistry, neuroticism has been studied associated to individual's oral health (63) and in relation to dental fear, especially in women (64-66). Anxiety is a clear predictor of avoiding dental treatment, as plenty of studies have shown this relationship (7, 44, 67-70). Root canal therapy is one of the dental treatments that most anxiety generates in patients (71). In our study, general anxiety variables and dental anxiety variables were assessed. Both of them had a strong correlation with subjetive dental avoidance. In particular, when both were compared in relation to avoidance, dental anxiety proved to be more predictive. At this point, we ought to highlight the role of dental fear and its vicious circle (72, 73). It is already known that dental fear has a prevalence of between 5 and 20% in the adult population and is a significant clinical complication in dental practice (65). Dental fear has been widely studied as a key predictor of dental avoidance (5, 6, 11, 21, 74-76).

This study presents some limitations that must be taken into account. These findings cannot be generalized due to the sample size being small and collected only in Spain, which is one of the countries of the European Union with higher rates of dental avoidance among adults (Healthcare activities statistics, https://ec.europa.eu/eurostat). It should be mentioned that there could be a possible bias in the present study due to 74% of the patients having undergone previous endodontic treatment. Finally, at a methodological level, it is necessary to point out the low but acceptable Cronbach´ alpha of the phobia module of IDAF-4C+, although this limitation can be found in other articles (77-78).

Conclusions

According to our results, dental anxiety plays the most important role in predicting root canal therapy avoidance. Therefore, we believe that the use of the dental anxiety scale would be enough to screen patients for high rates of avoidance.

Clinical Relevance

Managing anxiety, customizing treatment plans to promote a safe and calm environment at dental appointments, and discussing patient concerns prior to treatment is one way to reduce dental anxiety, also contributing to reduce avoidance of root canal therapy.

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Conflict of interest

None.

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ORIGINAL ARTICLE

Effect of continuous irrigation on apical transportation, centering ability and volume of removed dentin in curved root canals: a micro computed tomography study

ABSTRACT

Aim: *To assess the effect of continuous irrigation (CI) on apical transportation, centering ability and volume of removed dentin during root canal shaping with different file systems using micro-computed tomography (micro-CT).*
Methodology: *Twenty mandibular molars with a curvature of 25-35° were included. The teeth were scanned with micro-CT before shaping procedures and randomly divided into 4 groups (5 teeth, 10 canals) as follows: CI and WaveOne Gold (CI-WOG), CI and Hyflex EDM (CI-HEDM), Traditional irrigation and WaveOne Gold (T-WOG) and Traditional irrigation and Hyflex EDM (T-HEDM). Following root canal shaping procedures, all the teeth were re-scanned with micro-CT. Apical transportation and centering ability were evaluated through axial sections at the level of 1, 2, 3, 5 and 7 mm from the apical foramen. The amount of dentin removed was also analyzed by using micro-CT.*
Results: *The CI-WOG and CI-HEDM groups resulted in significantly less apical transportation at 7 mm bucco-lingually compared to the T-WOG group. The CI-HEDM group was able to stay bucco-lingually centered at 7 mm significantly more than the T-WOG group. No statistically significant difference was observed among the groups in terms of the volume of removed dentin.*
Conclusion: *It can be concluded that CI caused less apical transportation and better centering ability at 7 mm level in bucco-lingual direction.*

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Introduction

Cleaning of pulp and necrotic tissue residues, intracanal disinfection, biomechanical shaping, and hermetic root canal filling are important for the success of endodontic treatment (1). The morphology of the root canal is also critical to the success of root canal treatment as canal curvature is a factor that complicates treatment (2, 3). During the shaping of the curved root canal, iatrogenic problems such as apical transportation, ledge formation, perforation and failure in canal centering can be observed (4). In order to prevent such procedural errors, many different endodontic files with high flexibility and high cyclic fatigue resistance operating with rotation or reciprocating motion have been developed (5). There are many studies examining the ability of rotational or reciprocating files to induce apical transportation and centering ability, all of which report conflicting results (6-8). The shaping ability of the root canal file indicates that it can expand in taper, starting from the coronal part of the canal and narrowing towards the apex. The centering ability describes the ability of the root canal file to stay aligned with the canal axis during shaping (9). Endodontic files should show these features without producing errors such as ledges or perforations.

Root canal disinfection is important for eliminating of bacteria from the root canal system. It has been demonstrated that root canal is harbored with detectable amounts of bacteria after shaping procedures (10). Irrigation procedures such as irrigation agitation techniques and the CI method have been proposed to increase the effectiveness of irrigation solutions in the root canal (11). The application of the CI method during root canal shaping can aid in avoiding inadequate irrigation. However, there is no study in the literature examining the effect of CI on root canal shaping. Therefore, the aim of this study is to compare CI and traditional irrigation methods in terms of apical transportation and centering ability during root canal shaping with various endodontic files that working different movement principle. The null hypothesis was that there would not be a significant difference between the CI and traditional syringe irrigation groups.

Material and Methods

Selection of the samples

Ethical approval was obtained from the Ethical committee of University of A. The study was funded by the University of Atatürk with a grant number of TDH-2020-8678. The power analysis was performed based on the data of a previous study to obtain sample size (12). The sample size was determined using GPower 3.1.9.2 software and was estimated at n = 9 samples in each group by considering a=0.05, a study power of 80%.

In this study, 20 mandibular first molar teeth, which were extracted for periodontal reasons, were used and the mesio-buccal and mesio-lingual canals were examined.

The teeth to be included in the study were examined by cone-beam computed tomography. Teeth in the curvature class of mesio-buccal and mesio-lingual canal were selected according to the Schneider (13) method.

Inclusion Criteria:

1. no calcification of the root canal,
2. wide restoration or absence of caries in the tooth,
3. curvature of root canals between 25-35°,
4. not having had root canal treatment before,
5. no root resorption,
6. no root fracture or crack,
7. no pulp stones,
8. mature root,
9. adequate root length.

Exclusion Criteria:

1. calcification of root canal,
2. having had prosthetic treatment,
3. having straight roots,
4. having large root canal morphology,
5. root resorption,
6. vertical root fracture,
7. presence of pulp stone,
8. immature root,
9. inadequate root length.

Preparation of samples
The selected specimens were mechanically and ultrasonically cleaned of debris and soft tissue residues. Then, the teeth were disinfected in a solution containing 0.1% thymol and subsequently stored in saline. In order to distinguish the buccolingual aspect of the teeth, the buccal parts were marked with diamond burs.
The teeth were numbered and 20 were randomly divided into 4 groups (n=5) before starting the procedure using a website (www.randomizer.org). The 4 groups with these 5 teeth (10 canals for each group) are as follow.

1. CI and WaveOne Gold (CI-WOG)
2. CI and Hyflex EDM (CI-HEDM)
3. Traditional irrigation and WaveOne Gold (T-WOG)
4. Traditional irrigation and Hyflex EDM (T-HEDM)

Imaging with Micro-CT before Shaping
The teeth were scanned with a micro-CT device (Bruker Skyscan 1272, Billerica, Massachusetts, ABD) to obtain images before shaping (Figure 1). Scanning was done using 92 kV and 108µA settings and with 180° rotation around the vertical axis and a rotation step of 0.3°. The pixel size of the images is 16 µm. Scanning time for each sample took approximately 1 hour and 20 minutes.

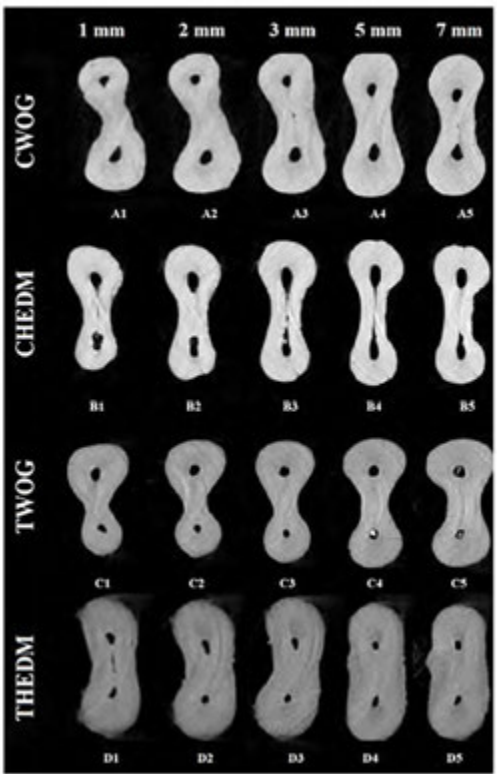


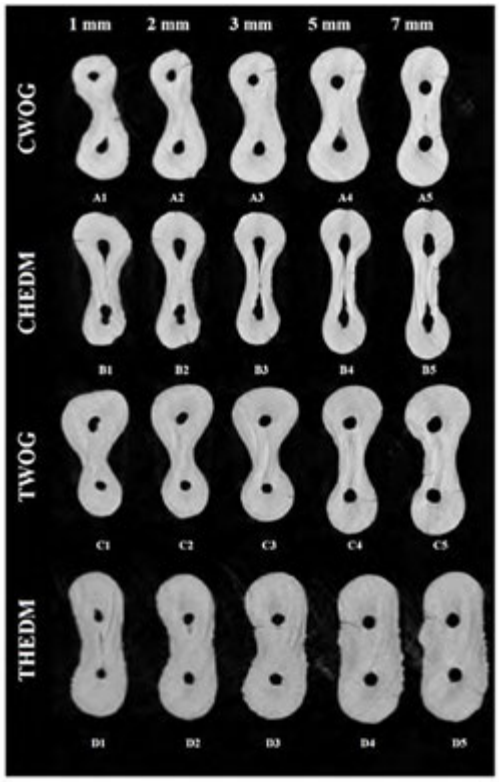
Figure 1
Sample Micro-CT Images of Pre-Shaping.

Access cavity preparation and root canal shaping
All procedures were performed by a single operator. A traditional cavity was opened using a diamond round bur. A #10 K-file was inserted into the root canal until its tip was visible at the major apical foramen, and the working length was determined by subtracting 1 mm from this length. In this study, 2 canals were excluded because one #10 K-type hand file (Mani Inc., Tochigi-Ken, Japan) was broken in each of the CI-HEDM and T-WOG file groups during canal length determination.

Canal shaping with continuous irrigation
In the CI group, a glide path was established using #10 and #15 K-files, respectively. The pump of the Self-Adjusting File (SAF; Re-Dent-Nova, Ra'anana, Israel) device was fixed to the endo-motor for canal shaping in the CI group. The flow rate of the SAF device was set to 10 ml/min. The WOG Primary file was used in "WaveOne ALL" mode with the VDW Silver Reciproc Endo-Motor (VDW GmbH, Munich, Germany). The HyFlex EDM OneFile file was used with the VDW Silver Reciproc Endo-Motor to perform a full rotation with 500 rpm and 2.5 Ncm torque. Shaping was performed with sodium hypochlorite (NaOCl) (Clinix, Dental Sky, UK) at room temperature for 30 seconds at each canal. Final irrigation was performed with 5 ml NaOCl at room temperature with a 31G disposable side-ventedneedle (Ultradent, South Jordan, UT) tip. A total of 10 ml of NaOCl was used for irrigation. The file was cleaned after every 3 pecking motions. These processes were continued until the working length was reached. Each file was used only once.

Canal shaping with traditional irrigation
In the traditional irrigation group, a glide path was established using #10 and #15 K-files, respectively. The WOG Primary file

Figure 2
Sample Micro-CT Images after Shaping.



was used in "WaveOne ALL" mode with the VDW Silver Reciproc Endo-Motor. The HyFlex EDM OneFile file was used with the VDW Silver Reciproc Endo-Motor to perform a full rotation with 500 rpm and 2.5 Ncm torque.
After every 3 pecking movements, 2 ml of 2.5% NaOCl was irrigated into the canal using a 31G disposable side-vented needle. Irrigation was completed with a total of 10 ml of NaOCl. The file was cleaned after each use. The canal was prepared with an apico-coronal motion until the working length was reached. Each file was used only once.
After the canals were shaped, a second set of images were obtained by scanning using the same parameters as the first scans (Figure 2).

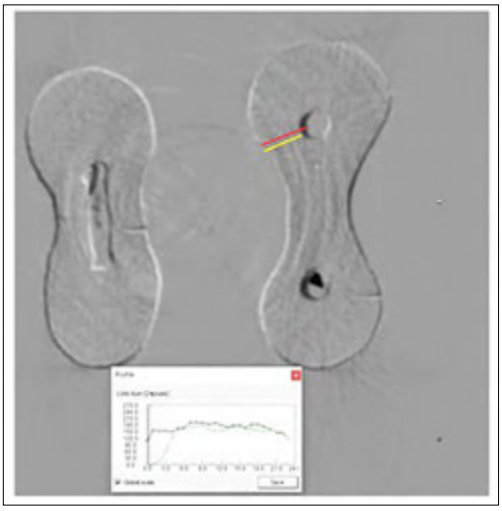


Figure 3
Sample Measurements before and after Shaping.

Evaluation of apical transport and canal centering ability
The 3D registration function of the Data-Viewer v.1.5.4.0 program was used to superimpose the pre- and post-instrumentation images (Figure 3).
Apical transportation was assessed using axial sections at 1, 2, 3, 5, and 7 mm distance from the apex of the tooth. The amount of transportation due to shaping in the apical region of the canal was calculated by subtracting the distance between the canal and the outer wall after shaping from the distance between the canal and the outer wall before shaping.
Centering ability was also evaluated using axial slices at 1, 2, 3, 5, and 7 mm from the apex of the tooth. The canal centering abilities were evaluated by rationing the distance between the canal and the outer wall before shaping and the distance between the canal and the outer wall after shaping.
The following formulas were used for apical transportation (AT) and centering abilities (CA):

$$AT=(B1–B2)–(L1–L2) \text{ and } (M1–M2)–(D1–D2)$$

$$CA=(B1–B2)/(L1–L2) \text{ and } (M1–M2)/(D1–D2)$$

A positive AT value indicates that the canal is carried in the buccal or mesial direction, while a negative value indicates that the canal is carried in the lingual or distal direction. An AT value of zero means that the canal expands equally in all directions.
The CA value represents a ratio. When calculating the CA value, the smaller number is written in the numerator. This value ranges from 0 to 1. If this value is close to 0, it deviates from the center, if it is close to 1, it remains in the center.

Statistical analysis
The SPSS 18.0 (SPPS Inc, Chicago, IL, USA) statistical package program was used for the evaluation of the study data. The Shapiro-Wilk test was used to determine whether the data showed normal distribution or not. The groups showing homogeneous distribution according to the result of the Levene test were evaluated using a one-way Anova test, which is a parametric test, to determine whether there was a statistically significant difference. Groups that did not show homogeneous distribution according to the results of Levene's test were evaluated with the Kruskal-Wallis test, which is a non-parametric test, to determine statistical significance. A % 95 confidence interval (P=0.05) was used in the evaluation of all data.

Results

Apical transportation
According to the results of the statistical analyses, no significant differences were observed between the groups in the mesio-distal direction in terms of apical transport values (Table 1).
While there was no significant difference in terms of apical transportation at 1, 2, 3, and 5 mm bucco-lingually a significant difference was observed between the CI-WOG and T-WOG groups at 7 mm bucco-lingually (Table 2).
The CI-WOG group caused significantly less apical transport at 7 mm bucco-lingually compared to the T-WOG group. At the same time, a significant difference was observed between the CI-HEDM and TWOG at 7 mm bucco-lingually. The CI-HEDM group caused significantly less apical transport at 7 mm compared to the T-WOG group.

Centering ability
No significant differences were observed between the groups in terms of centering abilities mesio-distally (Table 3). While no significant difference was observed in bucco-lingually centering abilities at 1, 2, 3, and 5 mm, a statistically significant difference was observed between the CI-HEDM and T-WOG in terms of bucco-lingually centering abilities at 7 mm (Table 4). The CI-HEDM group was able to stay bucco-lingually centered at 7 mm significantly more than the T-WOG group.

Volume of dentin
The volumes of dentin removed were also evaluated and it was observed that the volumes of dentin removed was similar between the groups, no statistically significant difference was observed (Table 5).

Discussion

In this study, the root canal shaping ability of Ni-Ti rotary file systems, which work with two different movement principles, with traditional syringe and CI methods, were evaluated using micro-CT. The null hypothesis was rejected as the CI technique showed less apical transportation and better centering ability compared to the traditional syringe irrigation technique.
It is known that root canal irrigation has

Table 1
Mean ± standard deviation values of apical transportation in the mesio-distal direction

Groups	1 mm	2 mm	3 mm	5 mm	7 mm
CWOG	0.06 ± 0.04	0.04 ± 0.03	0.06 ± 0.05	0.11 ±0.05	0.13 ± 0.11
CHEDM	0.04 ± 0.04	0.06 ± 0.05	0.06 ± 0.05	0.12 ± 0.14	0.15 ± 0.2
TWOG	0.09 ± 0.07	0.07 ± 0.05	0.09 ± 0.11	0.1 ± 0.12	0.24 ± 0.24
THEDM	0.11 ± 0.15	0.1 ± 0.15	0.04 ± 0.03	0.1 ± 0.08	0.14 ± 0.11
P Value	*0.582*	*0.548*	*0.121*	*0.771*	***0.121***

Table 2
Mean ± standard deviation values of apical transportation in the bucco-lingual direction

Groups	1 mm	2 mm	3 mm	5 mm	7 mm
CWOG	0.07 ± 0.05	0.09 ± 0.08	0.11 ± 0.09	0.13 ±0.12	0.05[a] ± 0.02
CHEDM	0.08 ± 0.06	0.07 ± 0.06	0.1 ± 0.05	0.09 ± 0.06	0.07[a] ± 0.5
TWOG	0.1 ± 0.09	0.12 ± 0.04	0.06 ± 0.03	0.12 ± 0.15	0.21[b] ± 0.1
THEDM	0.04 ± 0.05	0.09 ± 0.09	0.09 ± 0.08	0.14 ± 0.13	0.15[ab] ± 0.15
P Value	*0.347*	*0.319*	*0.576*	*0.771*	***0.005***

Different superscript letters indicate statistically significant differences between groups.

Table 3
Mean ± standard deviation values of centering ability in the mesio-distal direction

Groups	1 mm	2 mm	3 mm	5 mm	7 mm
CWOG	0.4 ± 0.3	0.57 ± 0.29	0.49 ± 0.22	0.45 ±0.24	0.43 ± 0.24
CHEDM	0.42 ± 0.21	0.48 ± 0.27	0.48 ± 0.36	0.4 ± 0.29	0.5 ± 0.33
TWOG	0.32 ± 0.19	0.37 ± 0.21	0.41 ± 0.31	0.46 ± 0.32	0.32 ± 0.21
THEDM	0.51 ± 0.39	0.53 ± 0.28	0.73 ± 0.22	0.19 ± 0.52	0.57 ± 0.23
P Value	*0.548*	*0.431*	*0.097*	*0.902*	***0.263***

an effect on apical transportation during root canal shaping (14). However, there is no study examining the effect of CI on root canal shaping. According to the results of this study, significantly less apical transportation was observed in the 7 mm bucco-lingually CI-WOG group compared to the T-WOG group. This result shows that, despite using the same file, preparation with CI offers a better shaping ability. It is known that the removal of debris during root canal shaping reduces the risk of apical transportation due to debris accumulation (15). Less apical transportation in the CI group may be explained by the removal of debris by Ci solution replacement depending on the technique (16). Previous research has shown that delivering CI solution into the canal with the SAF system, which is similar to the CI tech-

Table 4
Mean ± standard deviation values of centering ability in the bucco-lingual direction

Groups	1 mm	2 mm	3 mm	5 mm	7 mm
CWOG	0.34 ± 0.28	0.32 ± 0.27	0.32 ± 0.25	0.35 ±0.26	0.33ab ± 0.25
CHEDM	0.27 ± 0.16	0.52 ± 0.31	0.25 ± 0.17	0.42 ± 0.22	0.59a ± 0.24
TWOG	0.46 ± 0.29	0.28 ± 0.19	0.48 ± 0.26	0.51 ± 0.28	0.24b ± 0.18
THEDM	0.46 ± 0.29	0.44 ± 0.25	0.17 ± 0.47	0.36 ± 0.24	0.38ab ± 0.18
P Value	*0.336*	*0.314*	*0.056*	*0.509*	***0.025***

Different superscript letters indicate statistically significant differences between groups.

Table 5
Mean ± standard deviation values of the amount of dentin removed.

Groups	N	Mean	Std. Deviation
CWOG	10	0.852	0.456
CHEDM	9	1.297	0.410
TWOG	9	1.252	0.378
THEDM	10	1.163	0.511

nique, is effective in removing the debris residues (17). It is believed that the CI system used in this study provides CI solution into the canal, facilitating the extrusion of debris coronally, and thus creating a lubricating effect. This could be the reason for less apical transportation.
It has been reported that the SAF system, which has a working principle similar to the CI system, may cause inadequate irrigation in the apical area (18). In one study examining the effectiveness of the Quantec-E CI system for smear layer removal and canal cleaning, significant results were obtained only in the coronal region (19). Based on these findings, the fact that this study produced a significant result at 7 mm can be attributed to the facts that the flow of the solution is greater in the coronal region and that root canal curvature begins in the coronal region.
In addition, significantly less apical transportation and better centering ability were observed in the 7 mm buccolingual CI-HEDM group compared to the T-WOG group based on the results of the current study. Single file systems working with-continuous rotation and reciprocating motion were used to evaluate the effect of CI technique on canal shaping ability in this study. No significant differences were observed between the traditional syringe irrigation groups with HEDM and WOG files in apical transportation and canal centering ability. One study in the literature used simulated S-shaped resin block canals to compare the shaping ability of WaveOne Gold Primary, Hyflex EDM OneFile, and Reciproc R25 files. No statistically significant difference was observed between the WaveOne Gold Primary and Hyflex EDM OneFile files (20). Another study on simulated L-shaped resin block canals compared Protaper Universal, Protaper Next, Hyflex CM, Hyflex EDM, and WaveOne Gold files for apical transportation and observed no difference in apical transportation between the WaveOne Gold and Hyflex EDM file groups (21). Similar to the results of these studies, in the present study, no difference was observed between the WOG and HEDM files in traditional syringe irrigation groups in terms of shaping abilities. However, when the HEDM file was used with the CI technique, it has exhibited less apical transportation and better centering ability than the WOG file used with traditional syringe irrigation. These findings show that the CI technique has a positive effect on the root canal shaping ability by providing fewer procedural mistakes.
Centering ability is affected by root canal anatomy, the design and alloy of the root canal file, and the shaping technique with the canal file (22). In the literature, there are studies showing that continuous rotation movement in root canal shaping creates less apical transportation compared to files working with reciprocating movement (23). There are also studies showing that the reciprocating motion preserves the root canal anatomy better than the continuous rotation motion (24).
Several studies have evaluated the effects of file kinematics, taper, and design features on canal shaping ability (9, 26). In the present study, the Hyflex EDM working with continuous rotation motion and the WaveOne Gold Primary file working with

reciprocating motion were used with both traditional syringe irrigation and CI techniques. While no significant difference was observed between the HEDM and WOG files used with the traditional syringe irrigation method, the HEDM file used with the CI technique showed significantly less apical transportation and better centering ability compared to the WOG file used with the traditional syringe irrigation technique. The CI technique and the design differences of the files could be factors in this result. While there was no significant difference between the T-HEDM and T-WOG groups when the centering ability was evaluated, the CI-HEDM group showed better centering ability compared to the T-WOG group, showing that the CI technique had a positive effect on the centering ability.

The biggest issue in the use of extracted human teeth is their anatomically variability. In order to minimize these variables, the mesial canals of mandibular first molars, which have similar anatomical features as much as possible, were used. Apical patency control was provided with a #15 K-file to closely select the apical foramen width of each canal. Teeth in which the #15 K-file could reach the apex were selected. Although an attempt was made to minimize variables in this way, it is not possible to standardize them completely. Failure to achieve this standardization is the main limitation of the study.

Finally, the results of this study showed that dentin volumes removed in the CI and traditional syringe irrigation groups were similar. There is no a previous study comparing the amount of dentin removed using WOG and HEDM files. Therefore, there is no other study to which the dentin removal rates of WOG and HEDM files can be compared. However, according to a study, there was no statistically significant difference between rotary and reciprocating files in terms of the canal volume changes. This finding is in consistent with the results of the present study (27). In addition, in another study in which the ProTaper file was used with full rotation and reciprocal motion and canal volume change was compared, no significant difference was observed between the two groups (28). At the same time, a further study evaluating the canal volume change of full rotational motion and reciprocal motion observed no statistically significant difference between the 2 groups (29). The finding of the amount of dentin removed in this present study supports this information in the literature. In addition, this finding can be evaluated as a first since there is no study in the literature comparing the amount of dentin removed using WOG and HEDM files. Further studies examining the effect of the CI technique taking into account different variables are needed.

Conclusion

Within the limitations of the study, it can be concluded that CI technique caused less apical transportation and better centering ability at 7 mm level in bucco-lingual direction.

Clinical Relevance

This is the first study revealed that root canal shaping under continuous irrigation results in less canal transportation and improves the centering ability of the file.

Conflict of Interest

The authors declare that there is no any conflict of interest.

Acknowledgements

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ORIGINAL ARTICLE

A laboratory study analysis of the cyclic fatigue strength of glide path instruments at simulated body temperature

ABSTRACT

Aim: *This study aimed to evaluate the cyclic flexural fatigue resistance of four glide path files (one rotary and three reciprocating) by using a simulated root canal model.*

Methodology: *25-mm-length files (n=10) (ProGlider, Dentsply Maillefer; X1-Glide Path, MK Life; WaveOne Gold Glider, Dentsply Maillefer; and R-Pilot, VDW) were mounted in a 6:1 reduction handpiece powered by a torque-controlled motor and introduced into a 1.4-mm-diameter and 19-mm-length stainless steel tube (9-mm-length curved segment with an 86-degree curvature angle. The files were worked under irrigation with 37 °C distilled water until visual and/or audible observation of fracture. The time to each file fracture was measured with aid of a digital stopwatch. X1-Glide Path, WaveOne Gold Glider, and R-Pilot files were subjected to reciprocating motion while ProGlider files were subjected to continuous 300-rpm clockwise rotation. The surface morphology of two specimens per group was observed under scanning electron microscopy before and after fatigue testing. The file types were compared using one-way ANOVA and posthoc Tukey ($p<0.05$). The Weibull analysis was used to determine the expected lifespan of the files.*

Results: *The mean time to file fracture was found significantly different among file types ($p<0.001$): X1-Glide Path (455.32 sec) > R-Pilot (315.13 sec) > WaveOne Gold Glider (235.65 sec) > ProGlider files (158.30 sec). The Weibull analysis confirmed that ProGlider and X1-Glide Path files are associated with the shortest and the longest mean time to failure, respectively.*

Conclusion: *X1-Glide Path files showed significantly higher cyclic flexural fatigue resistance than other file types.*

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Introduction

Manufacturing technology of root canal shaping files has significantly changed in terms of nickel-titanium (NiTi) alloy and geometry to improve their mechanical performance (1); however, unexpected file fractures can still occur due to deformations and high-stress levels. Torsional failure can occur when the file tip is locked and the shaft rotates, while cyclic flexural fatigue can occur when the file is submitted to repeated tensile and compressive stresses at the same point (2, 3).

The establishment of a glide path by widening the root canal with a small-sized flexible file aims to allow safe and clear passage of larger engine-driven files (4). The single-use rotatory glide path file ProGlider (Dentsply Maillefer, Ballaigues,

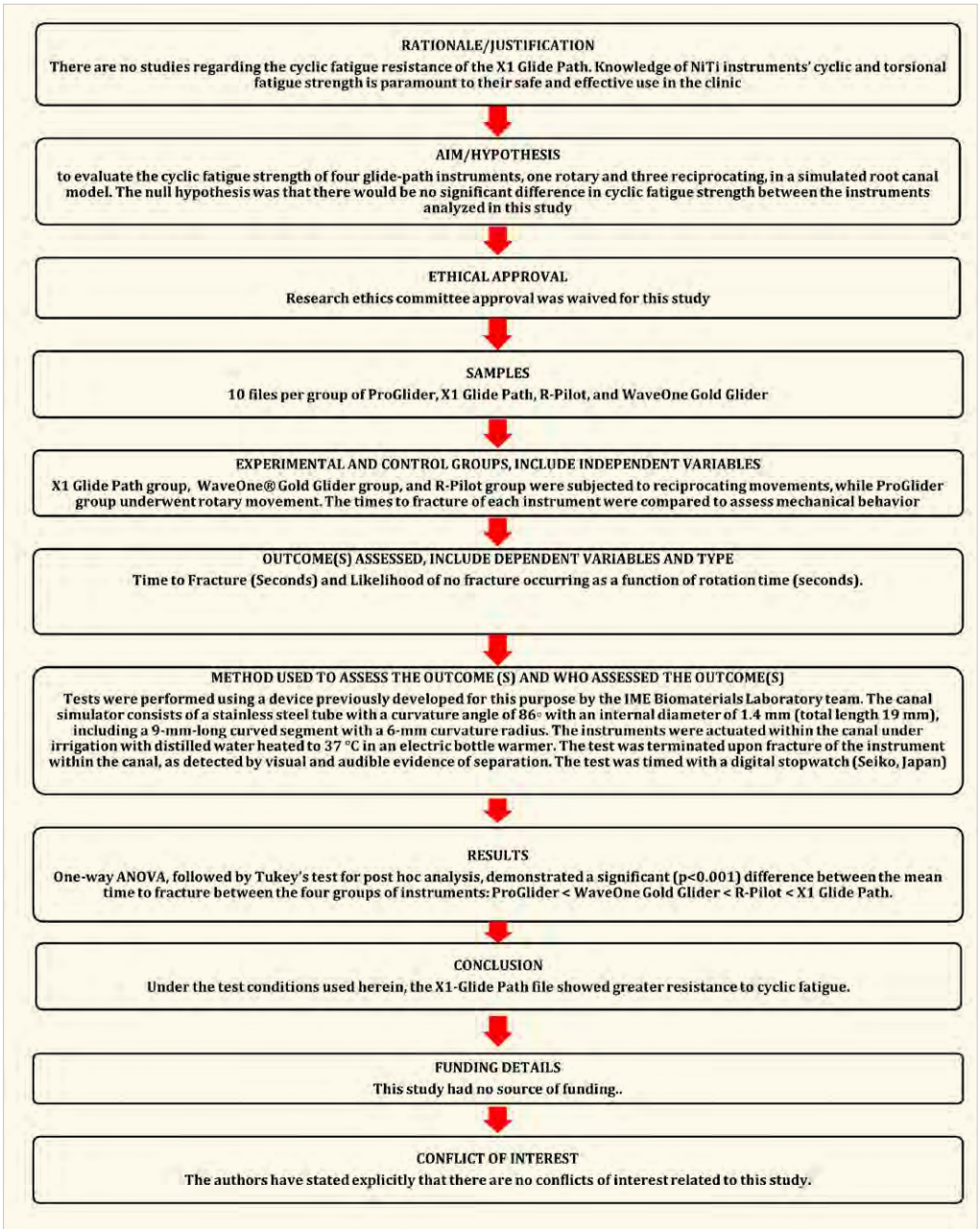

Figure 1
PRILE 2021 flowchart.

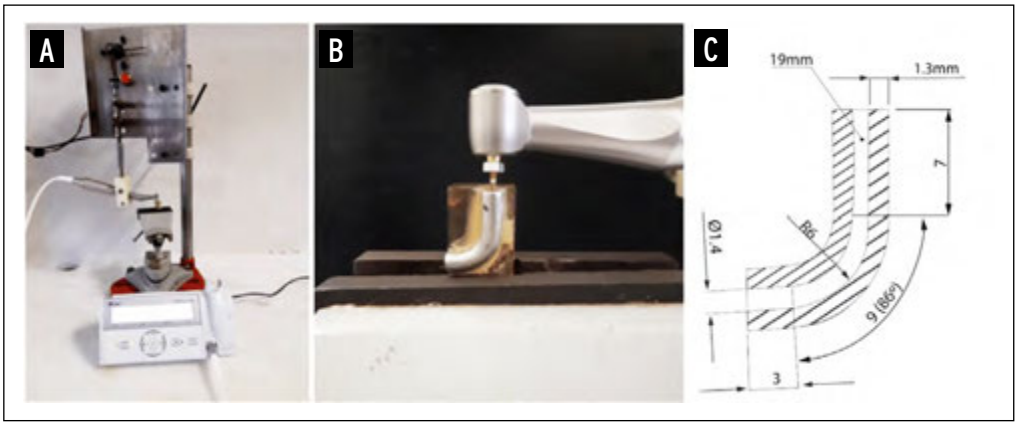

Figure 2
A) Apparatus used for fatigue testing; **B)** File placed into the artificial root canal; **C)** Dimensions of the artificial root canal.

Switzerland) is made with pre-heated NiTi (M-Wire technology), has a 0.16-mm-diameter tip, progressive taper design, square cross-section, and three different lengths (21, 25, and 31 mm) (5). The R-Pilot reciprocating glide path file (VDW, Munchën, Germany) is manufactured with M-Wire alloy and has a 0.125-mm-diameter tip, 4% constant taper, and S-shaped cross-section (6). The WaveOne Gold Glider reciprocating file (Dentsply Maillefer) is made with thermomechanically-treated alloy, has a 0.15-mm-diameter tip, 2 to 6% progressive taper, and parallelogram-shaped cross-section with two cutting edges (6). X1-Glide Path reciprocating files (MK Life, Porto Alegre, Brazil), are made with heated NiTi (Blue technology), have a controlled memory effect, have a 0.15-mm-diameter tip, 0.4-mm constant taper, 25-mm length, and square cross-section; however, there are still no studies on their cyclic flexural fatigue resistance.

Evidence of adequate mechanical behavior of NiTi files is essential to ensure their safe use in endodontics. Therefore, this study aimed to evaluate the cyclic flexural fatigue resistance of four glide path files (one rotary and three reciprocating) by using a simulated root canal model. The null hypothesis tested was that the file type does not have a significant influence on the cyclic flexural fatigue resistance.

Methodology

This study was reported by following the Preferred Reporting Items for Laboratory studies in Endodontology (PRILE) 2021 guidelines (Fig. 1) (7). The time to file fracture was considered the primary outcome of interest and the sample size of 10 specimens per group was based on Keskin et al. (6) with a power of 0.80 and significance level of 0.05 (G*Power 3.1.9.4; Universität Düsseldorf, Germany).

Cyclic flexural fatigue resistance testing of the 25-mm-length files (n=10) ProGlider (Dentsply Maillefer), X1-Glide Path (MK Life), WaveOne Gold Glider (Dentsply Maillefer), and R-Pilot (VDW) was performed at the Biomaterials Laboratory of the Military Institute of Engineering (Rio de Janeiro, Brazil). Each file was mounted in a static 6:1 reduction handpiece (Sirona, Bensheim, Germany) powered by a torque-controlled motor (Silver Reciproc; VDW) and introduced into an artificial canal held by a bench vise (Fig. 2A and 2B) previously described by Lopes et al. (8). The 19-mm-length stainless steel cylindrical tube had an internal diameter of 1.4 mm, including a 9-mm-length curved segment with a 6-mm curvature radius (86-degree curvature angle) (Fig. 2C). The files were worked under irrigation with distilled water heated at 37 °C with an electric bottle warmer until visual and/or audible observation of fracture. The time to each file fracture was measured with aid of a digital stopwatch (Seiko, Tokyo, Japan).

X1-Glide Path, WaveOne Gold Glider, and R-Pilot files were subjected to reciprocating motion (150-degree counterclockwise rotation followed by 30-degree clockwise) that needs three motor activations to

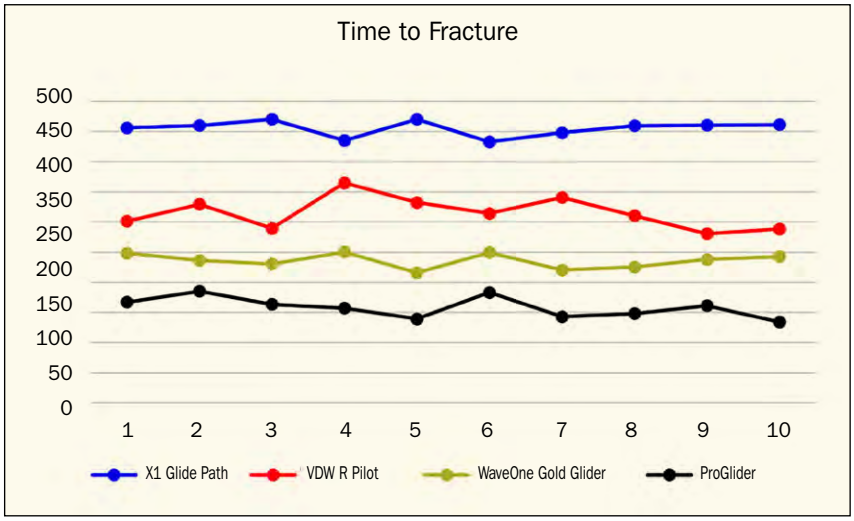

Figure 3
Time (sec) to file fracture for each specimen during cyclic flexural fatigue resistance testing.

complete a full 360-degree file rotation. ProGlider files were subjected to continuous 300-rpm clockwise rotation at a maximum torque of 2 N·cm. The surface morphology of two random specimens per group (www.randomizer.org) was observed under scanning electron microscopy (FEI Quanta FEG250; Thermo Fisher, Waltham, MA, USA) before and after fatigue testing.
The Kolmogorov-Smirnov test was used to assess the normal distribution of the data (jamovi v. 1.6.21, The jamovi project 2021) and the file types were compared using one-way analysis of variance (ANOVA) and posthoc Tukey multiple comparisons at a significance level of $p<0.05$. In addition, the Weibull analysis was used to determine the expected lifespan of the files (9).

Results

The mean time to file fracture was found significantly different among file types ($p<0.001$) (Table 1 and Figure 3).
The Weibull analysis confirmed that ProGlider and X1-Glide Path files are associated with the shortest and the longest mean time to failure, respectively. The coefficient of the Weibull equation indicates the reliability and homogeneity of the file's behavior (the higher the number, the smaller the results dispersion, and the greater the reliability).
R-Pilot: Probability of survival = -0.0396 sec +13.01
WaveOne Gold Glider: Probability of survival = -0.0883 sec +21.324
X1-Glide Path: Probability of survival = -0.0793 sec +36.673
ProGlider: Probability of survival = -0.0612 sec +10.209
The surface morphology of the files after cyclic flexural fatigue resistance testing is shown in Figures 4 and 5. All file types presented similar morphology with machining grooves of different extensions (Figures 6-8).

Discussion

This study compared the cyclic fatigue resistance of four glide path files through a well-established method reported by several studies (10-13). Since the X1-Glide Path file showed higher

Table 1

Mean time to file fracture during cyclic flexural fatigue resistance testing

File	Mean time to file fracture (sec)	Standard deviation	Standard error
X1-Glide Path	455.32[A]	12.983	4.1057
R-Pilot	315.13[B]	26.628	8.4204
WaveOne Gold Glider	235.65[C]	12.387	3.917
ProGlider	158.3[D]	17.44	5.5149

**Groups with the same capital letter are not significantly different (one-way ANOVA and Tukey multiple comparisons, p< 0.05). Different letters show significant differences between file types.*

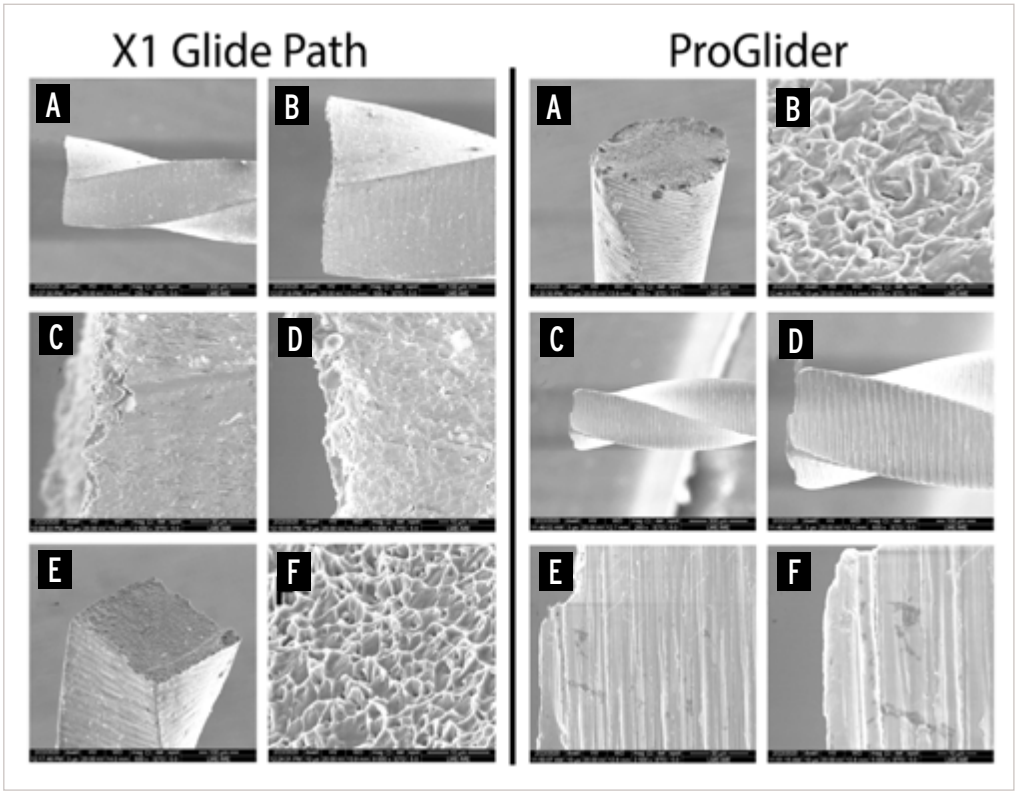

Figure 4
Manufacturing machining marks were observed on the tip surface morphology of X1-Glide Path and ProGlider files after fatigue cyclic flexural fatigue resistance testing. Lateral view at 250x **A)**, 500x **B)**, 2,500x **C)**, and 5,000x **D)** magnification. Upper view at 500x **E)** and 8,000x **F)** magnification.

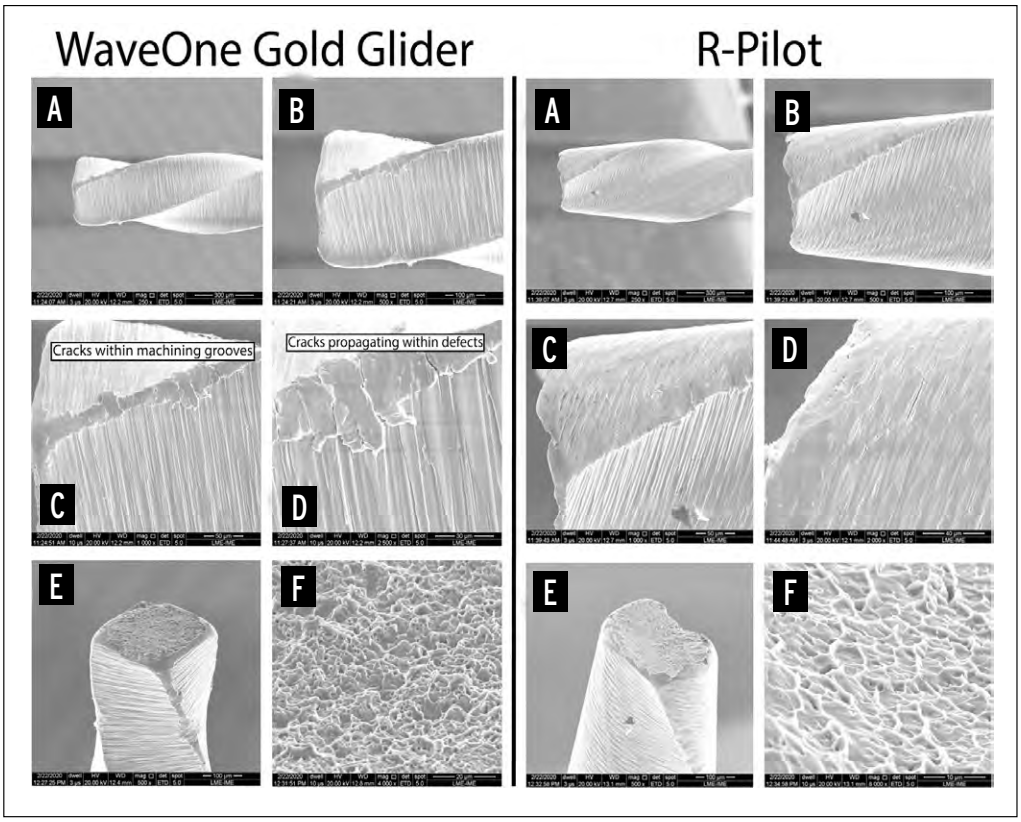

Figure 5
Surface morphology of fractured sites of WaveOne Gold Glider (cracks can be observed at the bottom of machining grooves) and R-Pilot (several cracks can be observed within the manufacturing machining marks) files after cyclic flexural fatigue resistance testing. Lateral view at 250x **A)**, 500x **B)**, 2,500x **C)**, and 5,000x **D)** magnification. Upper view at 500x **E)** and 8,000x **F)** magnification.

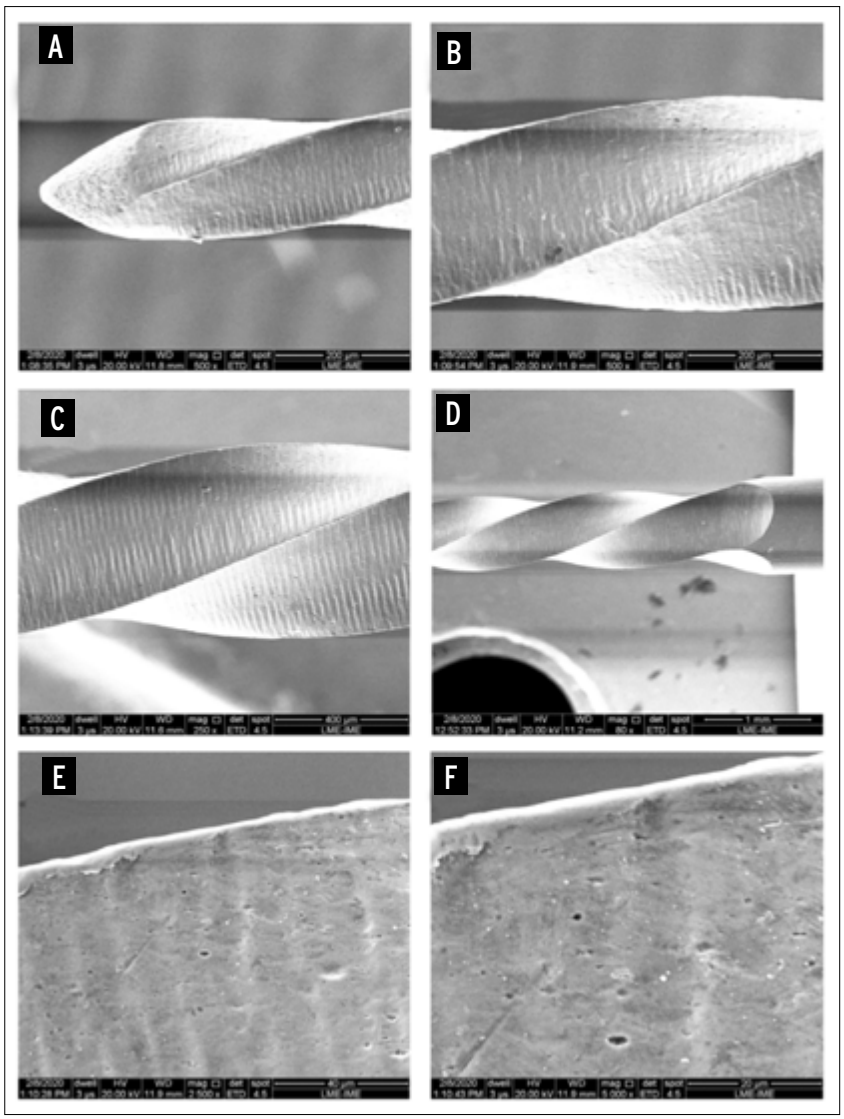

Figure 6
Morphology of the apical, middle, proximal, and 6.0 mm distant region (D6) of the X1 Glide Path® file before fatigue testing. Tooling marks left by the instruments manufacturing process are visible. **A)** Morphology 6.0mm distant region (D6) of the X1 Glide Path file before fatigue testing. Mag 500x. **B)** Morphology 6.0mm distant region (D6) of the X1 Glide Path file before fatigue testing, Mag 500x. **C)** Morphology 6.0mm distant region (D6) of the X1 Glide Path file before fatigue testing. Mag 250x. **D)** Morphology 6.0mm distant region (D6) of the X1 Glide Path file before fatigue testing. Mag 80x. **E)** Morphology6.0mm distant region (D6) of the X1 Glide Path file before fatigue testing. Mag 2500x. **F)** Morphology6.0mm distant region (D6) of the X1 Glide Path file before fatigue testing. Mag 5000x.

cyclic flexural fatigue resistance than other files, the null hypothesis had to be rejected. A static fatigue-testing model was used to avoid the root canal variations (angles and curvature length) of extracted human teeth (14, 15) as well as to eliminate operator-induced tensions (16). The use of a stainless steel tube to simulate the root canal has been reported to provide standardization and reliability to studies on the cyclic flexural fatigue resistance of NiTi files (17-19).

Pruett et al. (20) suggested the relevance of the radius of curvature as an independent variable of studies on root canal shaping. The authors observed that cycles to failure significantly decreased as the radius of curvature decreased due to increased tension and deformation of the files; in addition, all tested files fractured at the point of maximum flexure of the shaft that corresponds to the midpoint of the curvature. Therefore in this study, all file types were tested into the same artificial canal with an identical radius of curvature.

Kinematics has also been reported as a relevant variable in root canal shaping research since reciprocating glide path files have shown higher cyclic flexural fatigue resistance in comparison to rotary glide path files (21). Reciprocating files combine clockwise and counterclockwise movements to complete a rotation cycle; thus, stresses are released along the files and fracture strength is increased (22). The results of this study corroborate Serefoglu et al. (23), which also reported significantly lower cyclic flexural fatigue resistance for rotary files in comparison to reciprocating files.

The metal alloy, heat treatment, helical angle, cross-sectional shape, core mass, and dimensions also influence the flexibility and fatigue resistance of root shaping files (24). Heat-treated NiTi files (M-wire, Gold, or Blue technology) have been reported with higher flexural fatigue resistance than superelastic NiTi files due to superior mechanical properties (25); however, some studies have shown that these files are sensitive to temperature variation and have higher fracture strength at low temperatures (26, 27). The M-Wire technology applied in ProGlider and R-Pilot files relies on the reduction of transition temperature that maintains a high percentage of the

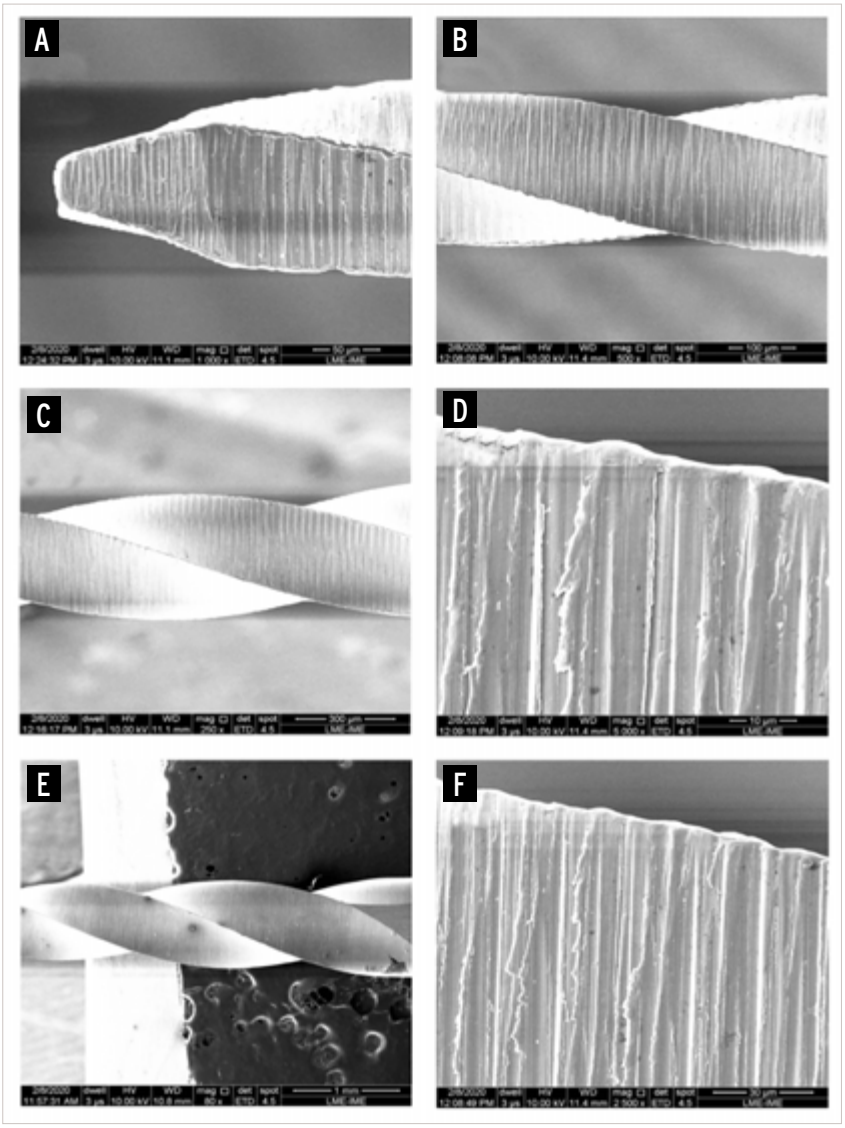

Figure 7
A) Morphology of the apical region, (D6) of the ProGlider file before fatigue testing. Tooling marks left by the instruments manufacturing process are visible. Mag 1000x. **B)** Morphology6.0mm distant region (D6) of the ProGlider file before fatigue testing. Mag 500x. **C)** Morphology6.0mm distant region (D6) of the ProGlider file before fatigue testing. Mag 250x. **D)** Morphology6.0mm distant region (D6) of the ProGlider file before fatigue testing. Mag 5000x. **E)** Morphology6.0mm distant region (D6) of the ProGlider file before fatigue testing. Mag 80x. **F)** Morphology-6.0mm distant region (D6) of the ProGlider file before fatigue testing. Mag 2500x. Mag 5000x.

martensite phase at room temperature. Conversely, X1-Glide Path files are heat-treated with Blue technology (28) and WaveOne Gold Glider files are treated with Gold technology, which can explain different cyclic flexural fatigue resistance results observed in this study. Klymus et al. (28) reported that X1-Glide Path and WaveOne Gold 25.07 files have similar cyclic flexural fatigue resistance at body temperature; however, in this study, the Blue-treated files showed significantly higher cyclic flexural fatigue resistance than both Gold-treated and M-wired files at 37 °C (body temperature). Therefore, further studies are encouraged to confirm the promising results of X1-Glide Path files and their clinical feasibility. This study is one of the few studies that determine the cyclic flexural fatigue resistance of NiTi engine-driven files by simulating the 37 °C body temperature observed in *in vivo* root canals (26).

In this study, both file types (X1-Glide Path and R-Pilot) manufactured with M-wire heat treatment showed the highest time to fracture; in addition, all files fractured approximately 8.5 mm from the tip (maximum shaft flexure), which corresponds to the midpoint of the canal curvature and corroborates with previous studies (29, 30) (Figure 6).

NiTi file's cross-sectional design and core diameter can increase their overall metal mass, and affect flexibility and fracture strength (31). However, in this study, two squared-shaped file types (X1-Glide Path and ProGlider) showed significantly different flexural fatigue resistance. Moreover, the results of this study corroborate Özyürek et al. (32), which observed higher flexural fatigue resistance for S-shaped files (R-Pilot) than WaveOne Gold Glider files (parallelogram-shaped files (WaveOne Gold Glider) due to less metal mass. Although laboratory studies cannot entirely simulate clinical conditions, their results can still provide substantial background knowledge.

Conclusion

X1-Glide Path files showed significantly higher cyclic flexural fatigue resistance than other file types. Further research is needed to validate these findings and provide safe and effective correlations for clinical practice.

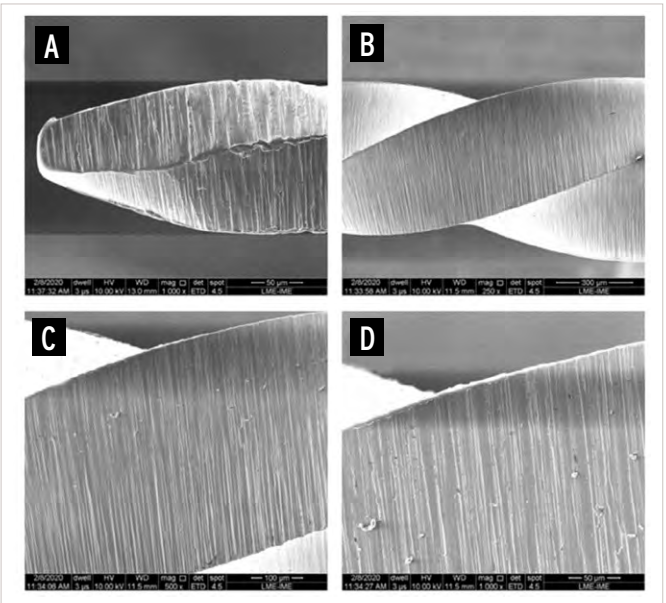

Figure 8
Morphology of the apical region and 6.0 mm distant region (D6) of the WaveOne Gold Glider® file before fatigue testing. Tooling marks left by the instrument manufacturing process are visible. **A)** Morphology of the apical region of the WaveOne Gold Glider® file before fatigue testing. Mag 1000x. **B)** Morphology 6.0 mm distant region (D6) of the WaveOne Gold Glider® file before fatigue testing. Mag 250 x. **C)** Morphology 6.0 mm distant region (D6) of the WaveOne Gold Glider® file before fatigue testing. Mag 500x. **D)** Morphology 6.0 mm distant region (D6) of the WaveOne Gold Glider® file before fatigue testing. Mag 1000x.

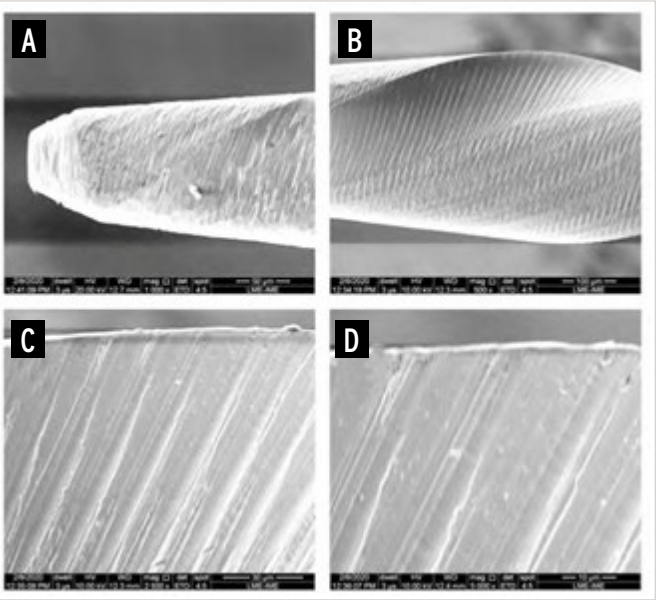

Figure 9
Morphology of the apical region and 6.0 mm distant region (D6) of the VDW R-Pilot® file before fatigue testing. Deep machining marks formed during the instrument manufacturing process are visible. **A)** Morphology of the apical region of the VDW R-Pilot® file before fatigue testing. Mag 1000x. **B)** Morphology 6.0 mm distant region (D6) of the VDW R-Pilot® file before fatigue testing. Mag 500x. **C)** Morphology 6.0 mm distant region (D6) of the VDW R-Pilot® file before fatigue testing. Mag 2500x. **D)** Morphology 6.0 mm distant region (D6) of the VDW R-Pilot® file before fatigue testing. Mag 5000x.

Clinical Relevance

Evidence of the proper mechanical behavior of glidepath files is essential to ensure their safe use in endodontics.

Conflict of Interest

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

Acknowledgements

None.

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Available online at www.giornaleitalianoendodonzia.it

ORIGINAL ARTICLE

Articles published in the Giornale Italiano di Endodonzia from 1987 to 2021: a bibliometric analysis

ABSTRACT

Aim: *The "Giornale italiano di Endodonzia" (GIE) is a peer-reviewed journal founded in 1987. It is the official journal of the Italian Society of Endodontics (SIE) and it is currently indexed in Scopus and Embase. In order to offer a comprehensive and quantitative evaluation of the scientific journal production, we carried out a bibliometric analysis of the complete collection of articles published on GIE.*

Methodology: *We searched the journal website archive for the non-indexed articles and Scopus database for the indexed articles published until March 2022. Relevant data were extracted from each article. Bibliometric analysis was performed using Biblioshiny, Publish and Perish and VOSviewer.*

Results: *A total of 601 documents were found, 246 (41%) of them were indexed in electronic databases. The annual production ranges from 4 (1987) to 37 (2021) with a mean annual growth rate of 6,76%. The most frequently published studies were in* vitro/ex vivo *studies. The total number of citations was 454. Dabelian 2016 was the most cited document with 29 citations. 1,177 different authors contributed with at least 1 article. Gagliani M was the most contributing author with 34 documents. The most cited author was Iandolo A with 78 citations. The most important contributing country was Italy, followed by Brazil and Iran. The most contributing institution was the University La Sapienza of Rome, followed by the University of Turin and the University of Naples. The most frequent keywords were "endodontics", "MTA", "CBCT", "cyclic fatigue" and "root canal treatment".*

Conclusions: *Bibliometric studies involve a rigorous process of analysis and classification of large volumes of bibliographic material to evaluate the impact of scientific publications, highlight the trend of topic interest and map the relationships between authors, documents, articles, affiliations and nations. GIE scientific production and number of citations have grown over the years. Some articles published on GIE had a moderate impact on the international literature. Alongside classic topics of interest, new "hot topics" have emerged regarding innovative materials and technologies.*

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Introduction

The Giornale Italiano di Endodonzia (GIE) was founded in 1987 and is the official journal of the Società Italiana di Endodonzia, SIE (Italian Society of Endodontics). Formerly named Giornale di Endodonzia, it is a peer-reviewed journal currently available only in electronic format. It publishes original scientific articles, reviews, clinical articles, case reports, book reviews, summaries, abstracts of scientific meetings and news in the field of Endodontology. GIE is indexed in Scopus (from 1990 to 1991 and from 2011 to now), Science Direct (from 2011 to 2018) and Embase (from 1990 to 1991 and from 2011 to now). Currently, it is published online by Ariesdue (Milan, Italy) and hosted by PAGEPress (Pavia, Italy), an Open Access scientific publisher. All articles are freely available on www.giornaleitalianoendodonzia.it. New articles are published monthly in the Early View section, while the full Journal is issued twice a year, in June and November. Considering the year 2020, GIE was the only Italian journal listed in CiteScore Rank for the category General Dentistry (Rank#89/111). Doubtless, it is the most important Italian journal concerning Endodontology and over the years has published the scientific contributions of the most famous Italian researchers and clinicians in this field. Since it was indexed in the major international biomedical databases, the number of potential readers and authors has greatly expanded. Bibliometrics, as firstly proposed by Pritchard in 1969, is the application of mathematics and statistical methods to books and other media of communications (1). In other words, is a process of analysis and classification of bibliographic material by framing representative summaries of the extant literature (2). Recently, several bibliometric analyses focused on the scientific production of selected dental journal have been published (3-5). This type of research is aimed at publishers and editors to assess the extent to which the journal performs, as long as at researchers and scholars to identify suitable journals for publication or potential collaborators and areas of research.

In 2022 GIE achieved its 35th year of publication and, to celebrate this anniversary, we want to offer, for the first time, a comprehensive evaluation of the scientific journal production in order to examine productivity, performance, publication trends, impact and mapping bibliometric networks.

Methodology

We searched the journal website archive for the non-indexed articles and the Scopus database for the indexed articles. Relevant data were manually extracted from each non-indexed article. Searching was carried out in March 2022. Articles were classified into 8 categories: 1 - original clinical studies (randomized controlled clinical trials, cohort studies, retrospective studies); 2 - *in vitro*, *ex-vivo*, animal original studies; 3 - systematic reviews; 4 - narrative reviews; 5 - case reports/case series; 6 - editorials, letters, communications, opinions; 7 - technical notes; 8 - surveys.

Bibliometric metadata of indexed articles were exported from Scopus in BibTex format to import in Biblioshiny software (6), in RIS format to import in Harzing's Publis or Perish software (PoP) (7) and in CSV format to import in VOSviewer software (8). Journal metrics (CiteScore, SCImago Journal Rank, Source Normalized Impact per Paper, h-index) were obtained and reported. The calculation of Citescore for the current year was based on the number of citations received by the journal in the latest four years, divided by the number of documents published in the journal in those four years (9). SCImago Journal Rank (SJR) is a measure of the scientific influence of scholarly journals that accounts for both the number of citations received by a journal and the importance or prestige of the journals where the citations come from (10). SJR indicator is a numeric value representing the average number of weighted citations received during a selected year per document published in the journal during

Table 1
Main information about GIE

Journal name	Giornale Italiano di Endodonzia Formerly Giornale di Endodonzia
Timespan	1987-2021
Current Publisher	Ariesdue Srl
Number of documents	601
Number of documents indexed in Scopus	246 (41%)
CiteScore	0,6
SJR 2020	0,160
SNIP 2020	0,260
Total citations	463
H-index	12
Authors	1,177

the previous three years, as indexed by Scopus. Higher SJR indicator values are meant to indicate greater journal prestige. Source Normalized Impact per Paper (SNIP) was calculated as the number of citations given in the present year to publications in the past three years divided by the total number of publications in the past three years (10). It is a metric that intrinsically accounts for field-specific differences in citation practices. The h-index measures the productivity and citation impact and it is the maximum value of h of such that the given author published at least h papers that have been cited at least h times (11). The publication trend by year, the annual growth rate and the citation trend by year were calculated and graphed. The production of publications by country was calculated and mapped with the dedicated function in Biblioshiny. The 10 most active affiliations as well as the most productive authors were identified and reported. Using PoP software the following data were reported for each author: total citations (TC), number of cited papers (NCP) and citations per cited paper (C/CP). C/CP was calculated by dividing the total number of citations by the total number of cited papers.
The 5 most cited articles were identified and reported. Co-authorship analysis was conducted with VOSviewer to measure the extent to which countries collaborated among them. Keywords analysis was done using WordCloud function of Biblioshiny. Analysis of co-occurrence of keywords was carried out with VOSviewer and showed selecting overlay visualisation.

Results

Main information were resumed in the Table 1. A total of 601 documents were found, with a mean of 17,7 documents per year. 246/601 articles (41%) were indexed in Scopus, while the remaining 355 were consulted on the online journal archive. Sixty-one studies were classified as original clinical studies, 276 as *in vitro*, *ex-vivo* or animal original studies; 4 as systematic reviews; 72 as narrative reviews; 93 as case reports/case series; 28 as editorials, letters, communications or opinions; 58 as technical notes; and 9 as surveys. The first randomized controlled clinical trial was published in 2004 (12).
1,177 different authors contributed with at least 1 article and 108 documents were single-authored. The annual production ranges from 4 (1987) to 37 (2021) with a mean annual growth rate of 6,76% (Fig. 1). The total number of citations, as reported by Scopus for indexed articles, was 454. 2016 was the year in which the articles with the highest number of citations (98) were published. The citations per citable years trend was reported in Figure 2. Regarding this parameter, 2016 was the year

Figure 1
Number of publications by year.

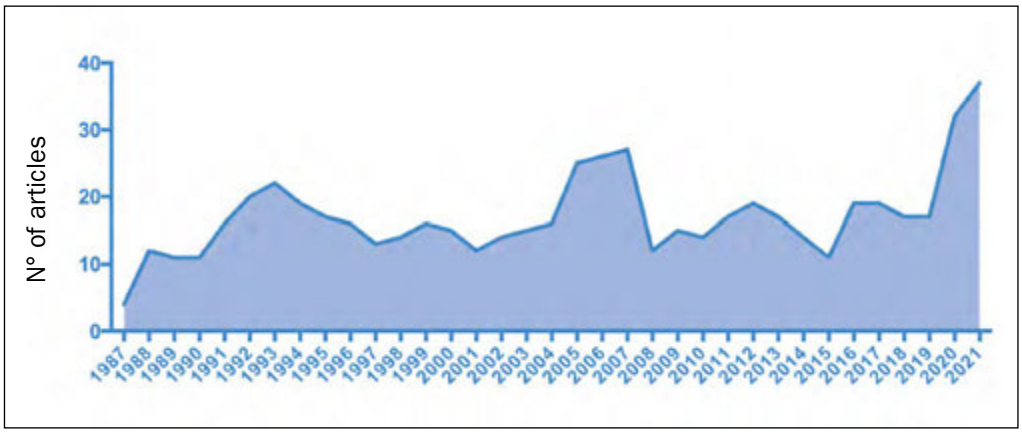
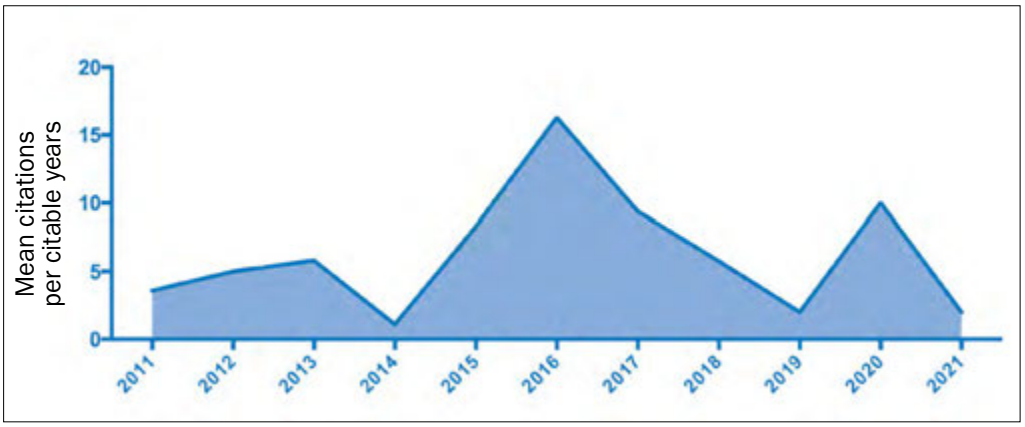


Figure 2
Citation trend by year. The "y" axis values were obtained by dividing the number of citations received by articles published in that year by the number of citable years (e.g. articles published in 2020 received 20 citations in 2 years, then the average citation per citable years is 10).



with the highest value, while 2014 was the year with the lowest value. As expected, Italy was the most important contributing country, followed by Brazil and Iran (Fig. 3).

The most contributing affiliations were Università La Sapienza di Roma, Università di Torino and Università di Napoli Federico II with 38, 29 and 26 documents,

Table 2
Top-10 most active authors

Author Name	N° of authored articles	Affiliation	Country
Gagliani M	34	Università degli Studi di Milano, Milan	Italy
Gambarini G	28	Università La Sapienza di Roma, Rome	Italy
Rengo S	28	Università degli Studi di Napoli Federico II, Naples	Italy
Berutti E	22	Università degli Studi di Torino, Turin	Italy
Malagnino VA	20	Università degli Studi G. d'Annunzio di Chieti, Chieti	Italy
Cavalleri G	19	Università di Verona, Verona	Italy
Gerosa R	19	Università di Verona, Verona	Italy
Plotino G	19	Private practice, Rome	Italy
Castellucci A	18	Private practice, Florence	Italy
Testori T	17	Università degli Studi di Milano, Milan	Italy

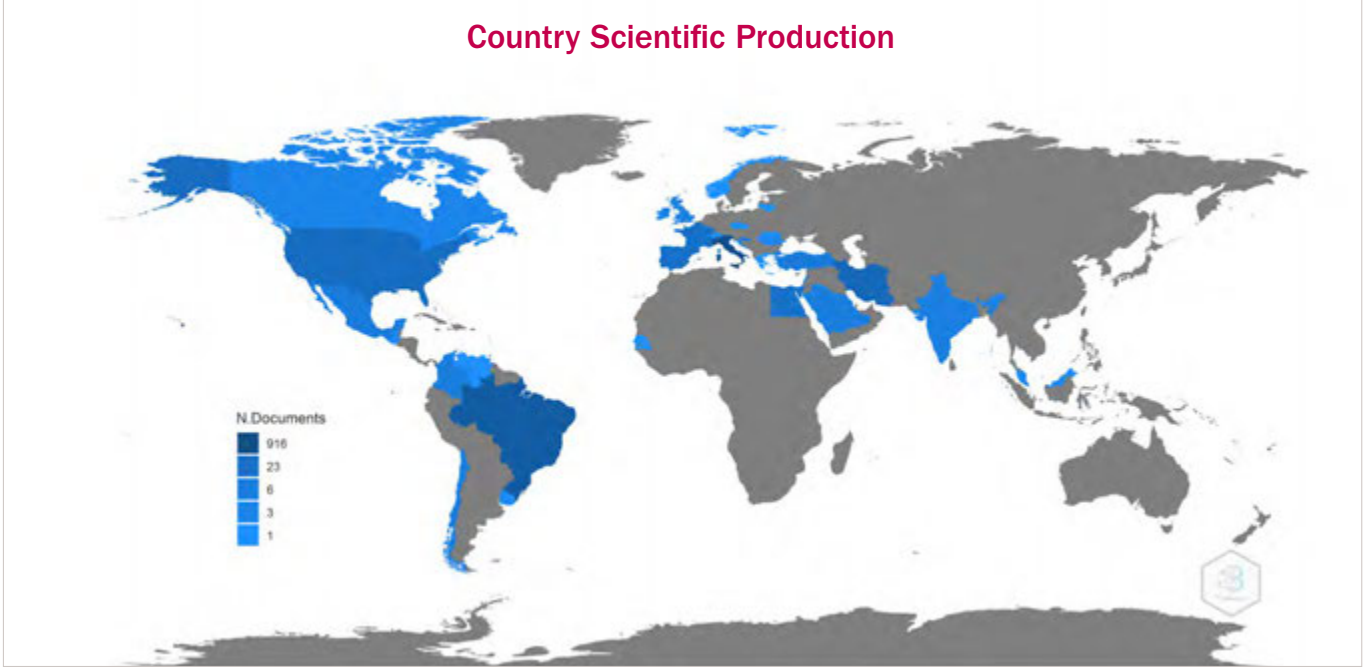


Figure 3
Distribution of scientific production by country.

respectively. The most productive authors were Gagliani M, Gambarini G and Rengo S with 34, 28 and 28 articles, respectively (Table 2). The most cited author was Iandolo A from Università degli Studi di Salerno with 78 citations. Metrics of the most cited authors are reported in Table 3. The article entitled "The use of premixed bioceramic materials in endodontics" by Dabelian et al. published in 2016 was the most cited document with 29 citations (13) (Table 4). Co-authorship analysis conducted at country level showed international collaborations of Italian authors with colleagues from Brazil, US, India, Egypt, Turkey and UK (Fig. 4). In the picture, the size of circles (items) relates to the production weight of each country, while the links connecting

Table 3
Top-10 most cited authors

Author name	Total citations	Affiliation	Country	NCP	C/CP
Iandolo A	74	Università degli Studi di Salerno, Salerno	Italy	8	9,3
Rengo S	48	Università degli Studi di Napoli Federico II, Naples	Italy	5	9,6
Gambarini G	48	Università La Sapienza di Roma, Rome	Italy	8	6
Plotino G	42	Private practive, Rome	Italy	9	4,7
Angerame D	37	Università degli Studi di Trieste, Trieste	Italy	6	6,2
Grande NM	29	Università Cattolica del Sacro Cuore, Rome	Italy	5	5,8
De Biasi M	22	Università degli Studi di Trieste, Trieste	Italy	5	4,4
Pappen FG	13	Universitade Federal de Pelotas, Pelotas	Brazil	3	4,3
Gagliani M	11	Univesità degli Studi di Milano, Milan	Italy	3	3,7
Berutti E	6	Università degli Studi di Torino, Turin	Italy	4	1,5

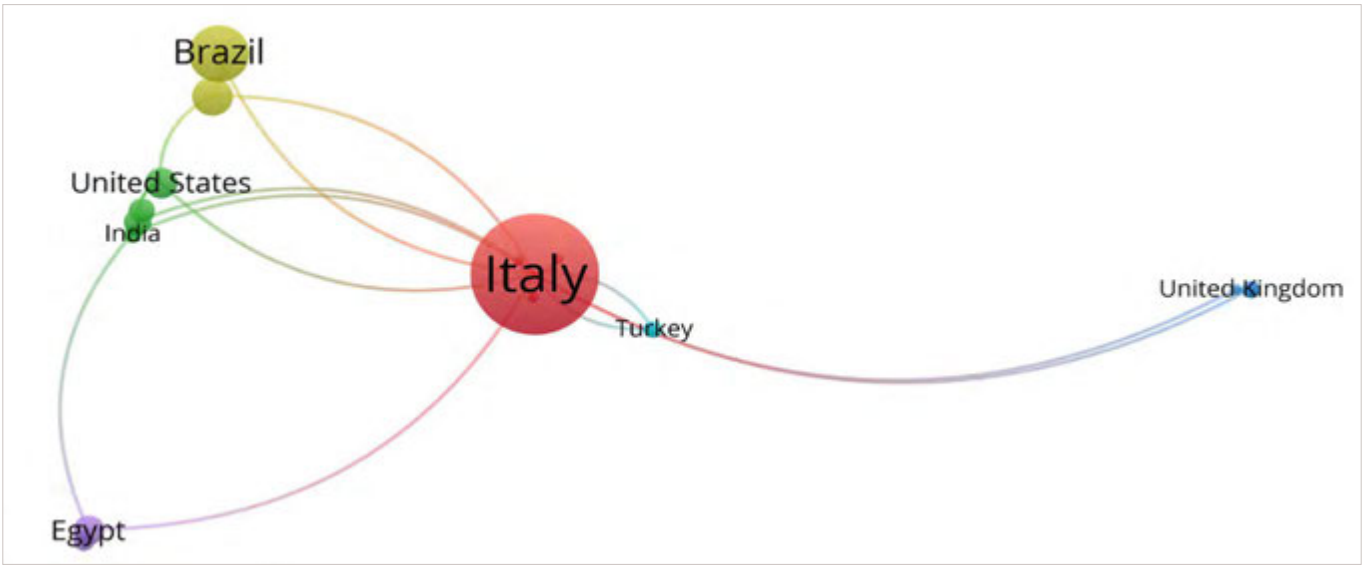
NCP: number of cited papers, C/CP: citations per cited papers.

Table 4
Top-5 most cited articles

Title	Authors	Year	Citations
The use of premixed bioceramic materials in endodontics (13)	Debelian G., Trope M.	2016	29
Cyst-like periapical lesion healing in an orthodontic patient: a case report with five-year follow-up (15)	Paduano S., Uomo R., Amato M., Riccitiello F., Simeone M., Valletta R.	2013	22
Biodentine: from biochemical and bioactive properties to clinical applications (14)	About I.	2016	21
Operating microscope: diffusion and limits (17)	Riccitiello F., Maddaloni G., D'Ambrosio C., Amato M., Rengo S., Simeone M.	2012	21
IG-File: a novel tool to improve root canal cleaning and measurement of the apical foramen (16)	Iandolo A., Ametrano G., Amato, M., Rengo S., Simeone M	2011	19

the circles refer to collaborations. The distance among the circles relates to the strength (frequency) of collaborations. The closest international collaboration of Italian authors was with colleagues from Turkey. The most frequent keywords were "endodontics", "MTA", "CBCT", "cyclic fatigue" and "root canal treatment" (Fig. 5). Co-occurrence keywords analysis was performed using VOSviewer software. The overlay visualization showed in Figure 6 report information regarding the weight of the single terms, the co-occurrence of them (links among circles) and the evolutions of terms over times. Keywords appeared more recently were coloured in yellow. While keywords such as "apexification", "composite", "microscope" and "gutta-percha" where used more frequently earlier in the time range considered, keywords such as "Wave one", "Protaper gold" and "pain" appeared later.

Figure 4
Co-authorship analysis conducted at country level.



Discussion

The Giornale Italiano di Endodonzia has been a reliable reference for more than thirty years for all general dentists practicing endodontics and for endodontic specialists. Initially aimed at

Figure 5
Most frequent author keywords showed as a wordcloud.

Italian readers, since it started publishing articles exclusively in English and was indexed on the main international databases, it has interested a greater number of readers, even outside the national borders. Likewise, foreign authors have considered GIE for publications of their research. In an era in which the quantification of scientific production and the analytical assessment of its impact are playing an increasing role, bibliometric analysis has progressively gained attention among scholars. The availability of freeware software to conduct such analyses, such as those utilized in this study, has greatly facilitated carrying out bibliometric investigations. Less than half of the studies published on GIE are indexed on Scopus, specifically the articles published from 1990 to 1991 and from 2011 to now. All the counts concerning the citations involved only the indexed articles, as it was not possible to trace the number of citations of the non-indexed articles. Most of the articles were signed by multiple authors and more than a thousand different authors authored at least one article. Many but not all the single-authored articles were Editorials. Eleven of the 34 articles by the most productive author (Gagliani M) were Editorials. The most cited author was Iandolo A.: his ten articles investigated cleaning with irrigant solutions, the resistance of modern NiTi instruments and technical aspects of root canal treatment. Two of the top-5 most cited articles, specifically the first and the third, are literature reviews dealing with the "new" calcium silicate hydraulic cements and were authored respectively by 2 American authors and 1 French author (13, 14). The second most cited article, authored by Italian researchers, was a case report of a successfully non-surgical root canal treatment of the upper central incisors associated with a large cist-like lesion in a patient undergoing orthodontic treatment (15). The fourth and the fifth most cited articles, both authored by Italian researchers, were respectively a survey on the use of the operating microscope in endodontics and an *in vitro* study on a new file created for sonic activation of irrigants and apical gauging (16, 17). The observation that the first three most cited articles are assignable at low levels of the hierarchy of evidence (literature reviews and case reports) leads to some considerations. A robust scientific methodology does not always correspond to a high impact in the literature (number of citations), in particular in journals such as GIE which are not aimed exclusively at those involved in research but also at clinicians involved in everyday practice. This fact should be kept in mind for example by young researchers who need citations to improve their bibliometric performances for advancement in their academic career.

Almost half of the published studies (46%) consisted of *in vitro* or *ex vivo* investigations plus a few studies conducted on animal models. The preferred study models were human extracted teeth. These types of studies are generally easier to conduct than clinical studies and allow to investigate the subject of research under strictly controlled conditions. On the other side, the conclusions obtained from these studies cannot always be transferred to the clinical situation. The second most frequent type of article was the case report/case series. This type of publication, although has little scientific value, is indicated for reporting peculiar cases due to the type of pathology, the clinical manifestations, the difficulty of treatment or the outcome of the therapy. This type of article is attractive

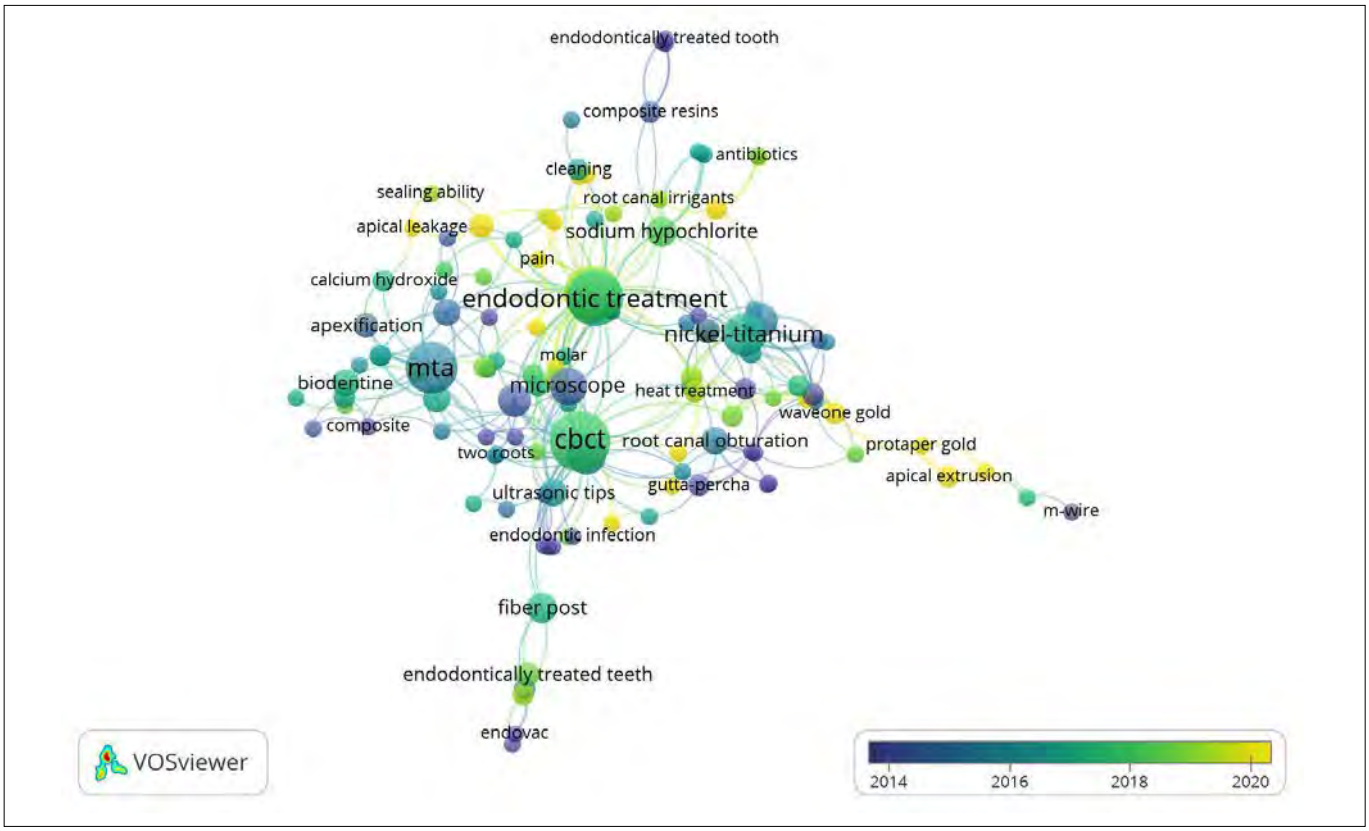


Figure 6
Co-occurrence keywords analysis.

mainly for clinicians who can draw useful lessons for their daily activities. The third most frequent type of article was the narrative review. In this type of article certain specific topics are addressed based on the available literature. Compared to the systematic review, the methodology to write a narrative review is far less rigorous, but it represents a very useful educational tool to get quick and comprehensive information about a specific topic. Considering that technical aspects are often crucial in endodontic practice, it is not surprising the high number of articles classified as technical notes. In this kind of publication particular techniques or instruments are described in detail, often accompanied by images or illustrations and clinical instructions. Looking at these articles sorted chronologically is a good way to get an overview of the historical development of endodontology.

Among the outputs of bibliometric investigations, the maps of network analyses are probably the most attractive. Using VOSviewer it is possible to construct and visualize the newtwork of documents, authors, affiliations or countries based on co-authorship, citation and co-citation relations. In the images provided by the software the distance between two items approximately indicated the relatedness of the items. A simple and straightforward method to represent the keywords most used by authors is the so called "word-cloud", which is the visual representation of words that give greater prominence to words that appear more frequently. A more sophisticated investigation of keywords is represented by the overlay visualization of the co-occurrence keywords analysis. In this map, the keywords that are used together are linked by a line. The distance between two keywords approximately indicated the grade of co-occurrence. The frequency of the keywords correlates with the size of the circles. The colour of the circles expresses the currentness of the keywords. Such analyses are useful to appreciate the emerging trend in research topics. Figure 5 shows that heat-treated alloy instruments have gained a lot of at-

tention in the very last few years, as long as classical topics such as infection, apical leakage and pain. Only a few years earlier, however, studies on the use of CBCT were prevalent. Even before that, the most frequently published studies focused on MTA.

Conclusions

A bibliometric study implies a rigorous process of analysis and classification of large volumes of bibliographic material to evaluate the impact of scientific publications, highlight the trend of topics of interest and map the relationships between documents, articles, affiliations and nations. In recent years, GIE has progressively consolidated on a process of internationalization. Some articles published on GIE had a moderate impact on the international literature. Alongside classic topics of interest, new "hot topics" have emerged regarding innovative materials and technologies. To continue the progressive strengthening of this journal in the international panorama, it will be important to attract international researchers to publish their solid scientific papers on GIE and we hope that this article contributes to this direction.

Clinical Relevance

GIE proves the progress of Italian endodontics over the last 35 years and has become attractive also to the international scientific community.

Conflict of Interest

None.

Acknowledgement

None.

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ORIGINAL ARTICLE

Evaluation of laser-activated irrigation on evidence-based endodontology: a bibliometric and scientometric analysis of recent articles

ABSTRACT

Aim: *To identify the research articles on laser use in endodontic irrigation in the last 5 years and conduct a bibliographic analysis.*
Materials & Methods: *A literature search was conducted through an online database, Web of Science, by using the Clarivate search engine. The search strategy was as follows in all fields including the database: the main keyword was "Endodontics" and the secondary were "Laser" and "irrigation". The time frame was limited to the last 5 years until May 2022. The search was restricted to mainly focusing on endodontics concerning laser-activated irrigation, therefore all papers were manually screened for inclusion. Title, first author, institute/country, number of authors, journal name, impact factor, year, citation, keywords, and abstracts were recorded. VOSviewer version 1.6.10 software was used to map the bibliometric network.*
Results: *A total of 30 articles published by indexed journals (Web of Science Index) between 2017-2022 years were included in the study. 17 countries contributed to the research and publications in the field, with/without collaborations. The most prolific country in the field is Türkiye with the highest contribution rates (33,3%). The highest number of publications was published by 'Photomedicine and Laser Surgery' with 6 articles.*
Conclusions: *The bibliometric analysis overviewed the current trends, leading journals, and countries in terms of the research focused on laser use in endodontic irrigation. The most-cited research articles related to laser use in endodontic irrigation have covered topics such as bactericidal effect, smear layer removal, pushout bond strength, growth factor release, and apical extrusion of irrigant.*

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KEYWORDS *bibliometric analysis, citations, endodontics, irrigation, laser*

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Introduction

Root canal treatment includes various steps such as preparation with various types of instruments, disinfection using chemical solutions, and filling the root canal space hermetically. Although it is possible to remove pulpal residues and microorganisms from the root canals by chemo-mechanical debridement (1-3), complete shaping and cleaning of the root canals are impossible due to the complex anatomy (4, 5). Areas that cannot be reached via instrumentation, such as the lateral canal and isthmus, may harbor tissue debris, microorganisms, and their by-products, preventing full adaptation of the obturation material and may cause persistent periradicular infections (6, 7). Therefore, it is crucial to ensure direct contact with the solution with the whole canal structure during irrigation, especially at the apical part of the root canals (8, 9).

Studies on new systems or techniques to ensure effective intracanal disinfection are still ongoing due to the inadequacy of using irrigation solutions without additional activation. Cavity preparation, pulp capping, canal disinfection, and activation of irrigation solutions are among the use of lasers in endodontics (10). Laser activation of irrigation solutions was found to be statistically significantly more effective in removing the smear layer compared to conventional techniques (11).

Bibliometrics uses quantitative measures to assess academic productivity. Citation analysis is a common method in the bibliography of the science and evaluates the impact of research papers by observing the number of citation data received by other scholarly works (12-14). Citation analysis highlights the trendy areas of research and hints at prospective areas of interest (15). This method has been applied to various aspects of endodontics and identified the contributing institutions, authors, and journals in relevant and novel fields including micro-CT use in endodontics and regenerative endodontics (16, 17). However, no bibliometric analysis of papers focusing on laser use in endodontic irrigation has been published. Therefore, this study aimed to analyze the papers focused on laser use in endodontic irrigation in the last 5 years.

Materials and Methods

A comprehensive systematic literature search was conducted to identify the related research in the field through an online database, Thomson Reuters Web of Science, by using the Clarivate search engine. The search strategy was as follows in all fields including the database: the main keyword was “Endodontics” and the secondary were “Laser” and “irrigation”. Keywords selection was conducted with the purpose of search optimization to locate every related publication. To reach current studies, the time frame was limited to the last 5 years until May 2022. The search was restricted to mainly focusing on endodontics concerning laser-activated irrigation, therefore all papers were manually screened for inclusion. Proceeding papers, editorial materials or letters, corrections, notes, and early access papers were excluded from the study. Each article was further reviewed, and basic information was collected, including the study design. The data with the full record and cited references were exported using the ‘tab-delimited file’ tool. Title, first author, institute/country, number of authors, journal name, impact factor, year, citation, keywords, and abstracts were recorded. VOSviewer version 1.6.10 software (Centre for Science and Technology Studies, Leiden University, Netherlands) was used to map the bibliometric network of the exported data that has an automatic term identification algorithm (downloadable at www.vosviewer.com).

Questions to be answered in line with the purpose of this study

1. What is the distribution of articles by year?
3. What is the distribution of the most contributing countries?
3. Which are the journals with the highest number of published articles in the field?
4. Who are the most cited authors and

which are the most cited publications?
5. Which type of laser is most commonly used for laser activation of irrigants in endodontics?

Results

A total of 30 articles published by indexed journals (Web of Science Index, SCI-E) between 2017-2022 years were included in the study. The distribution of publications by year was presented in Figure 1. Analysis of the country of origin using VOSviewer showed that 17 countries contributed to the research and publications in the field, with/without collaborations. The country contributions and the bibliographic coupling were presented in Figure 2. The highest contribution is from Türkiye with 9 articles. Figure 3 presented the paper count distribution published in the field and total citations. The highest number of publications is in the category of 'Engineering' and 'Medicine' with 6 articles published by 'Photomedicine and Laser Surgery', following 'The Journal of Endodontics' with 4 articles (Figure 3). A total of 150 authors were involved in publishing articles related to laser-activated irrigation and the most cited author is Chiniforush with a total of 77 citations by 3 documents, followed by Afkhami and Akbari with 49 citations in the field of subject.
Research focuses on included papers according to the keywords presented in Figure 4. The articles with research information and conclusions were presented in Table 1. According to the scientometric evaluation, the most focused laser type was Er: YAG, followed by diode-laser. The distribution of laser-type metrics was presented in Figure 5.

Table 1
List of the publications about laser use in endodontic irrigation (2017-2022)

Authors	Research Article	Journal	Institution (Corresponding author)	Times Cited, WoS Core	Times Cited, All Databases	Year	Laser	Conclusion
Afkhami, F; Akbari, S; Chiniforush, N	Enterococcus faecalis Elimination in Root Canals Using Silver Nanoparticles, Photodynamic Therapy, Diode Laser, or Laser-activated Nanoparticles: An In Vitro Study	Journal of endodontics	Tehran University of Medical Sciences	49	52	2017	Diode laser	PDT with indocyanine green photosensitizer, an 810-nm diode laser, and AgNPs have the potential to be used as an adjunct for disinfection of the root canal system.
Ghorbanzadeh, R; Assadian, H; Chiniforush, N; Parker, S; Pourakbari, B; Ehsani, B; Alikhani, MY; Bahador, A	Modulation of virulence in Enterococcus faecalis cells surviving antimicrobial photodynamic inactivation with reduced graphene oxide-curcumin: An ex vivo biofilm model	Photodiagnosis and photodynamic therapy	Tehran University of Medical Sciences	21	22	2020	Light-emitting diode	Reduced Graphene oxide-Curcumin-Photodynamic inactivation inhibited the biofilm formation ability and virulence activity of E. faecalis
Lukac, N; Jezersek, M	Amplification of pressure waves in laser-assisted endodontics with synchronized delivery of Er: YAG laser pulses	Lasers in medical science	University of Ljubljana	19	19	2018	Er: YAG	Amplification of cavitation bubbles was more apparent in canals with a smaller diameter.

Table 1

List of the publications about laser use in endodontic irrigation (2017-2022)

Authors	Research Article	Journal	Institution (Corresponding author)	Times Cited, WoS Core	Times Cited, All Databases	Year	Laser	Conclusion
Kirmali, O; Ustun, O; Kapdan, A; Kustarci, A	Evaluation of Various Pretreatments to Fiber Post on the Push-out Bond Strength of Root Canal Dentin	Journal of endodontics	Akdeniz University	18	20	2017	Nd: YAG	Nd: YAG laser-assisted irrigation with EDTA improved smear layer and debris removal.
Gokturk, H; Ozkocak, I; Buyukgebiz, F; Demir, O	Effectiveness of various irrigation protocols for the removal of calcium hydroxide from artificial standardized grooves	Journal of applied oral science	Gaziosmanpasa University	17	18	2017	Er: YAG	Laser-activated irrigation and Passive ultrasonic irrigation methods removed more calcium hydroxide than XP-endo Finisher, CanalBrush, Vibringe, and conventional syringe irrigation.
Golob, BS; Olivi, G; Vrabec, M; El Feghali, R; Parker, S; Benedicenti, S	Efficacy of Photon-induced Photoacoustic Streaming in the Reduction of Enterococcus faecalis within the Root Canal: Different Settings and Different Sodium Hypochlorite Concentrations	Journal of endodontics	University of Genoa	14	17	2017	Er: YAG	Er: YAG laser-activated irrigation with 5% NaOCl using PIPS technique led to effective removal of the bacterial biofilm and removal of the smear layer.
Passalidou, S; Calberson, F; De Bruyne, M; De Moor, R; Meire, MA	Debris Removal from the Mesial Root Canal System of Mandibular Molars with Laser-activated Irrigation	Journal of endodontics	University of Ghent	11	12	2018	Er: YAG	Er: YAG laser-assisted irrigation removed significantly more debris in the canals and the isthmus compared to needle irrigation.
Beltes, C; Economides, N; Sakkas, H; Papadopoulou, C; Lambrianidis, T	Evaluation of Antimicrobial Photodynamic Therapy Using Indocyanine Green and Near-Infrared Diode Laser Against Enterococcus faecalis in Infected Human Root Canals	Photomedicine and laser surgery	Aristotle University of Thessaloniki	11	14	2017	Diode laser	Photodynamic therapy with indocyanine green activated by a diode laser emitting NIR light (810 nm) is bactericidal to E. faecalis but is inferior to 2.5% NaOCl.
Cheng, XG; Tian, TT; Tian, Y; Xiang, DD; Qiu, J; Liu, XH; Yu, Q	Erbium: Yttrium Aluminum Garnet Laser-Activated Sodium Hypochlorite Irrigation: A Promising Procedure for Minimally Invasive Endodontics	Photomedicine and laser surgery	Air Force Military Medical University	9	12	2017	Er: YAG	Er: YAG activation of NaOCl with PIPS tip showed a similar disinfection effect to NaOCl alone at smaller apical terminal working widths.
Eymirli, A; Nagas, E; Uyanik, MO; Cehreli, ZC	Effect of Laser-Activated Irrigation with Ethylene Diaminetetraacetic Acid and Phytic Acid on the Removal of Calcium Hydroxide and Triple Antibiotic Paste from Root Dentin	Photomedicine and laser surgery	Hacettepe University	9	9	2017	Er, Cr: YSGG	Er, Cr: YSGG activation of EDTA and phytic acid completely removed triple antibiotic paste and effectively removed calcium hydroxide on root dentin

Table 1

List of the publications about laser use in endodontic irrigation (2017-2022)

Authors	Research Article	Journal	Institution (Corresponding author)	Times Cited, WoS Core	Times Cited, All Databases	Year	Laser	Conclusion
Korkut, E; Torlak, E; Gezgin, O; Ozer, H; Sener, Y	Antibacterial and Smear Layer Removal Efficacy of Er: YAG Laser Irradiation by Photon-Induced Photoacoustic Streaming in Primary Molar Root Canals: A Preliminary Study	Photomedicine and laser surgery	Necmettin Erbakan University	8	10	2018	Nd: YAG Diode laser Er: YAG laser	Irrigant activation by Nd: YAG, diode laser, and Er: YAG laser with PIPS resulted in a significantly higher reduction in the number of E. faecalis compared to the NaOCl group.
Pourhajibagher, M; Chiniforush, N; Bahador, A	Antimicrobial action of photoactivated C-phycocyanin against Enterococcus faecalis biofilms: Attenuation of a quorum-sensing system	Photodiagnosis and photodynamic therapy	Tehran University of Medical Sciences	7	7	2019	Diode laser	C-phycocyanin is an effective photosensitizer against biofilm of E. faecalis inside the root canal system
Nagas, E; Kucukkaya, S; Eymirli, A; Uyanik, MO; Cehreli, ZC	Effect of Laser-Activated Irrigation on the Push-Out Bond Strength of ProRoot Mineral Trioxide Aggregate and Biodentine in Furcal Perforations	Photomedicine and laser surgery	Hacettepe University	7	8	2017	Er, Cr: YSGG	Er, Cr: YSGG laser activation of irrigation has no detrimental effect on the push-out dentin bond strength of Biodentine and ProRoot MTA used in furcal perforation repair.
Ozbay, Y; Erdemir, A	Effect of several laser systems on the removal of smear layer with a variety of irrigation solutions	Microscopy research and technique	Kirikkale University	6	7	2018	Er, Cr: YSGG Nd: YAG Er: YAG	Er, Cr: YSGG, Nd: YAG, and Er: YAG laser with PIPS tip have almost similar efficiency in smear layer removal when used for activation of NaOCl and EDTA.
Turkel, E; Onay, EO; Ungor, M	Comparison of Three Final Irrigation Activation Techniques: Effects on Canal Cleanness, Smear Layer Removal, and Dentinal Tubule Penetration of Two Root Canal Sealers	Photomedicine and laser surgery	Baskent University	6	8	2017	Er: YAG	EndoVac system, laser activation with PIPS, and conventional syringe irrigation are similarly effective in debridement efficacy, smear layer removal, and dentinal tubule penetration.
Vidas, J; Snjaric, D; Braut, A; Carija, Z; Bukmir, RP; De Moor, RJG; Prso, IB	Comparison of apical irrigant solution extrusion among conventional and laser-activated endodontic irrigation	Lasers in medical science	University of Rijeka	5	7	2020	Er: YAG	Er: YAG laser-activated irrigation with PIPS fiber tip resulted in reduced endodontic irrigant extrusion compared with needle-syringe irrigation.
Betancourt, P; Merlos, A; Sierra, JM; Arnabat-Dominguez, J; Vinas, M	Er, Cr: YSGG Laser-Activated Irrigation and Passive Ultrasonic Irrigation: Comparison of Two Strategies for Root Canal Disinfection	Photo-biomodulation photomedicine and laser surgery	University of Barcelona	4	5	2020	Er, Cr: YSGG	Laser-assisted irrigation with Er, Cr: YSGG is more effective at improving the antimicrobial activity of 0.5% NaOCl than passive ultrasonic irrigation against intracanal biofilm.
Afhkami, F; Ahmadi, P; Chiniforush, N; Sooratgar, A	Effect of different activations of silver nanoparticle irrigants on the elimination of Enterococcus faecalis	Clinical oral investigations	Tehran University of Medical Sciences	3	3	2021	Er: YAG Diode laser	Activation with passive ultrasonic irrigation and Er: YAG laser activation with PIPS enhanced the efficacy of AgNP in the elimination of E. faecalis.

Table 1

List of the publications about laser use in endodontic irrigation (2017-2022)

Authors	Research Article	Journal	Institution (Corresponding author)	Times Cited, WoS Core	Times Cited, All Databases	Year	Laser	Conclusion
Mancini, M; Cerroni, L; Palopoli, P; Olivi, G; Olivi, M; Buoni, C; Cianconi, L	FESEM evaluation of smear layer removal from conservatively shaped canals: laser-activated irrigation (PIPS and SWEEPS) compared to sonic and passive ultrasonic activation-an ex vivo study	Bmc oral health	University of Rome Tor Vergata	3	3	2021	Er: YAG	Er: YAG laser-assisted activation with PIPS and SWEEPS techniques are superior to sonic activation in smear layer removal.
Su, Z; Li, ZB; Shen, Y; Bai, YH; Zheng, Y; Pan, C; Hou, BX	Characteristics of the Irrigant Flow in a Simulated Lateral Canal Under Two Typical Laser-Activated Irrigation Regimens	Lasers in surgery and medicine	Beihang University	2	2	2021	Er: YAG	Laser activation with PIPS, and SWEEPS techniques are better than ultrasonic-activated irrigation at delivering the irrigation solution into lateral canals.
Ayranci, F; Ayranci, LB; Ozdogan, A; Ozkan, S; Peker, MO; Aras, MH	Resistance to vertical root fracture of apicoected teeth using different devices during two root canal irrigation procedures	Lasers in medical science	Ordu University	2	2	2018	Er: YAG Diode laser	Diode laser activation of EDTA reduced the fracture resistance of the teeth.
Wen, C; Kong, YY; Zhao, J; Li, Y; Shen, Y; Yang, XC; Jiang, QZ	Effectiveness of photon-initiated photoacoustic streaming in root canal models with different diameters or tapers	Bmc oral health	Guangzhou Medical University	1	1	2021	Er: YAG	Er: YAG laser activation of 2% and 5.25% NaOCl with PIPS has better antibacterial and bacteriostatic effects than conventional needle irrigation.
Hancerliogullari, D; Erdemir, A; Kisa, U	The effect of different irrigation solutions and activation techniques on the expression of growth factors from dentine of extracted premolar teeth	International endodontic journal	Kırıkkale University	1	1	2021	Er: YAG	Er: YAG laser activation of EDTA or Citric acid with PIPS tip resulted in higher growth factor release than conventional syringe irrigation, and passive ultrasonic irrigation.
Wu, LX; Jiang, S; Ge, H; Cai, ZY; Huang, XJ; Zhang, CF	Effect of Optimized Irrigation With Photon-Induced Photoacoustic Streaming on Smear Layer Removal, Dentin Microhardness, Attachment Morphology, and Survival of the Stem Cells of Apical Papilla	Lasers in surgery and medicine	Fujian Medical University	1	1	2021	Er: YAG	Er: YAG laser with PIPS activation of EDTA for 40 seconds was able to remove the smear layer without reducing dentin microhardness and was beneficial for the attachment and survival of stem cells of the apical papilla.
Saricam, E; Kucuk, M; Akyol, M	Evaluation of EDTA, QMix, and Irritrol solutions activated with Er, Cr: YSGG and diode lasers on the push-out bond strength of filling material	Microscopy research and technique	Yıldırım Beyazıt University	1	1	2021	Er,Cr: YSGG Diode laser	Er, Cr: YSGG laser activation of QMix irrigation increased the bond strength of filling material.

Table 1
List of the publications about laser use in endodontic irrigation (2017-2022)

Authors	Research Article	Journal	Institution (Corresponding author)	Times Cited, WoS Core	Times Cited, All Databases	Year	Laser	Conclusion
Magni, E; Jaggi, M; Eggmann, F; Weiger, R; Connert, T	Apical pressures generated by several canal irrigation methods: A laboratory study in a maxillary central incisor with an open apex	International endodontic journal	University of Basel	1	1	2021	Er: YAG	Irrigation with EndoVac, Er: YAG laser activation, ultrasonically activated irrigation, the Self-adjusting file, and the XP-endo Finisher generated safer apical pressure levels than EDDY and RinsEndo in a simulated maxillary central incisor with an open apex.
Henninger, E; Berto, LA; Eick, S; Lussi, A; Neuhaus, KW	In Vitro Effect of Er:YAG Laser on Different Single and Mixed Microorganisms Being Associated with Endodontic Infections	Photo-biomodulation photomedicine and laser surgery	University of Basel	0	0	2019	Er: YAG	Laser activation of NaOCl has better antimicrobial efficiency when used with 600 micrometers conical PIPS tip than 300 micrometers tapered tip.
Wen, C; Yan, L; Kong, YY; Zhao, J; Li, Y; Jiang, QZ	The antibacterial efficacy of photon-initiated photoacoustic streaming in root canals with different diameters or tapers	Bmc oral health	Guangzhou Medical University	0	0	2021	Er: YAG	Er: YAG activation of 2% NaOCl with PIPS tip had a greater bactericidal effect in root canals with a smaller taper and width.
Todea, DCM; Luca, RE; Balabuc, CA; Miron, MI; Locovei, C; Mocuta, DE	Scanning electron microscopy evaluation of the root canal morphology after Er: YAG laser irradiation	Romanian journal of morphology and embryology	Victor Babes University of Medicine & Pharmacy	0	1	2018	Er: YAG	Er: YAG laser activation of 2.5% NaOCl with PIPS tips is effective at smear layer removal.
Onac, A; Florescu, A; Tudose, AD; Manea, S; Pangica, AM; Ionescu, TP; Biclesanu, C	Comparative SEM Study on the Effect of Irrigating the Radicular Dentine with NaOCl and EDTA Through Conventional Techniques and Diode Laser	Revista de chimie	Titu Maiorescu University of Bucharest	0	0	2017	Diode laser	Irrigation with 2% NaOCl and 17% EDTA activated diode laser is superior to conventional irrigation with the same irrigants in smear removal.

Discussion

Our study aimed to evaluate the impact of research regarding laser use in endodontic irrigation as a current concept in endodontics in the last 5 years by citation analysis. It was claimed that bibliometric analysis is supposed to be performed by including articles concerning classic topics and the scientific impact of the studies could be determined after many years of publications. However, it was shown that 73 of the 100 top-cited articles published in endodontic journals were published in the last 10 years, therefore it may be concluded that former studies are not necessarily to be with the highest impact (15, 18). Moreover, the fact that laser use in endodontic irrigation is a relatively novel phenomenon, the authors of this study believe that limiting the study to articles published in the last 5 years is not a drawback but rather a rational approach to include studies with the most cutting-edge equipment and therefore relevant study design.

Web of Science (WoS) is a popular database that has been used as a tool for citation analysis due to its broad database includes publications from way back to 1945 (19). WoS is not the only platform used for ac-

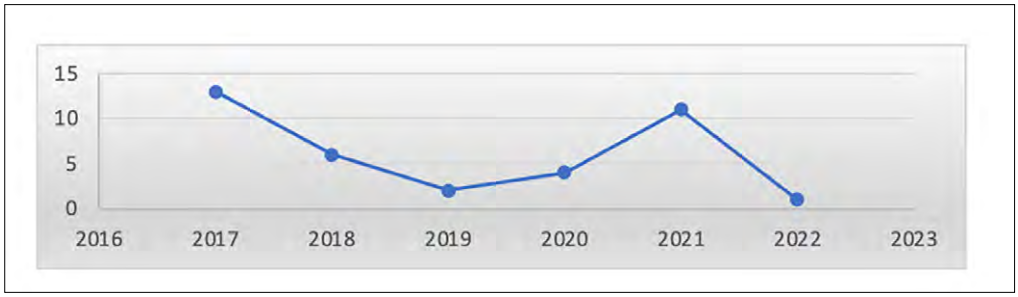


Figure 1
Distribution of publications by year.

ademic search. Google Scholar, includes citations from dissertations, conference reports, preprints, and books (18). Therefore, WoS was used to include and evaluate the articles, and Google Scholar was used to verify the number of citations concerning laser use in endodontic irrigation.

Photobiomodulation, Photomedicine, and Laser Surgery (formerly Photomedicine and Laser Surgery) was the journal in which the highest number of related articles were published. Topic-specific scope of the journal and indexing in Science Citation Index Expanded might be the attracting factors for researchers. Journal of Endodontics, which is considered one of the leading journals in endodontics, was the journal that published articles in the field with the second-highest number.

Based on the number of institutions of the corresponding author, it is observed that almost one-third of the articles were from Türkiye. This result is consistent with some previous studies concerning the fact that Türkiye is amongst the most contributing countries to endodontic literature (20, 21). This might be attributed to the increasing number of researchers interested in endodontics and study groups.

Based on the historical review of laser use, since the development of the ruby laser by Maiman (1960) and the application of the laser in endodontics by Weichman (1971), a variety of documents on potential applications for lasers in endodontology have been published (22). One of these applications is the laser doppler flowmeter used for diagnostic purposes. This laser technique measures the number and velocity

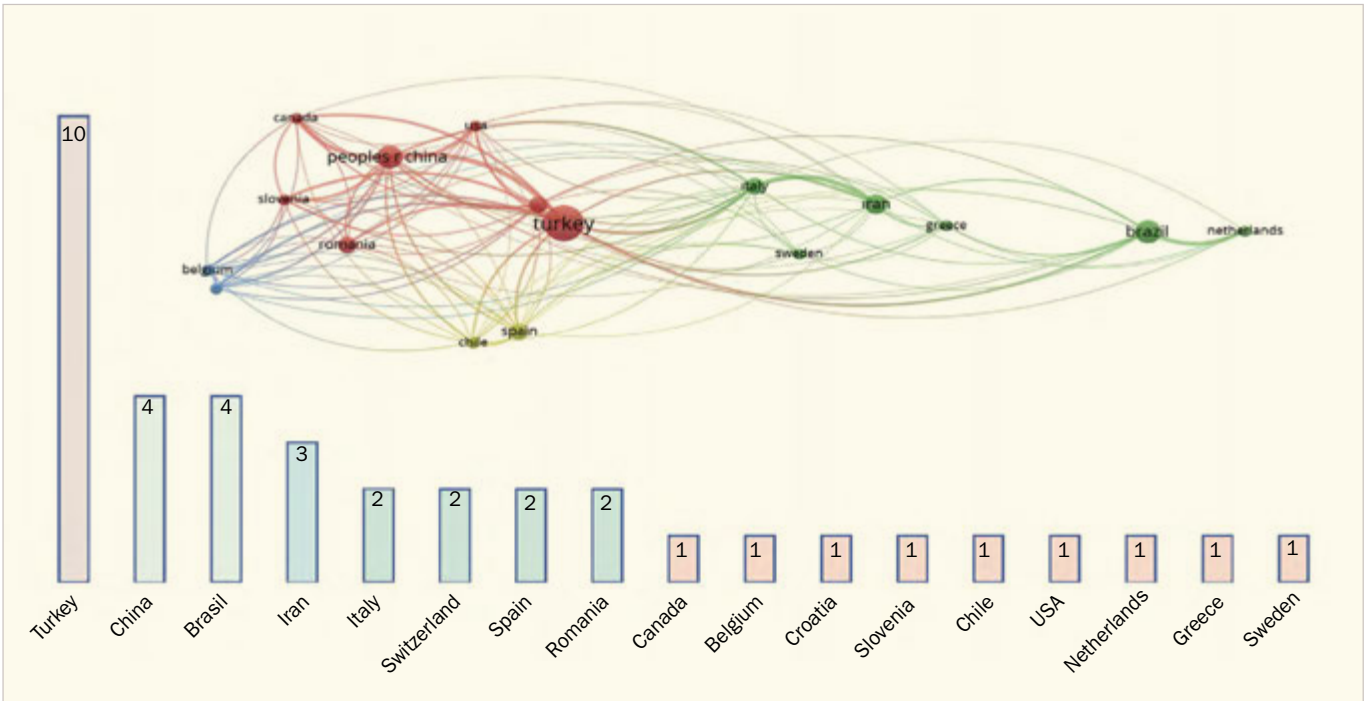
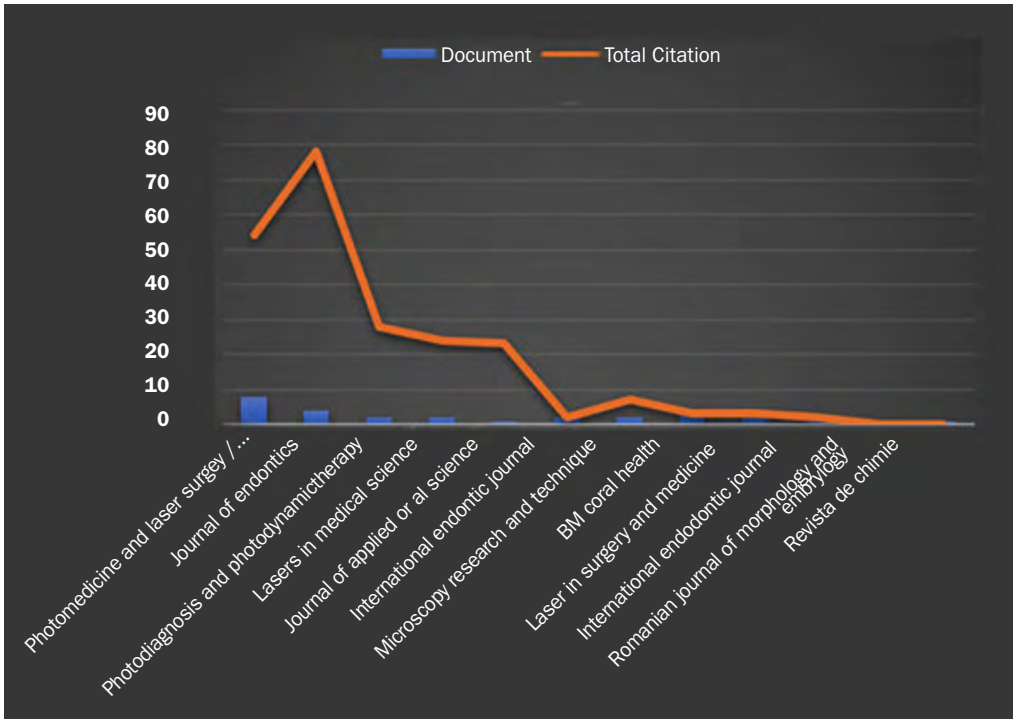


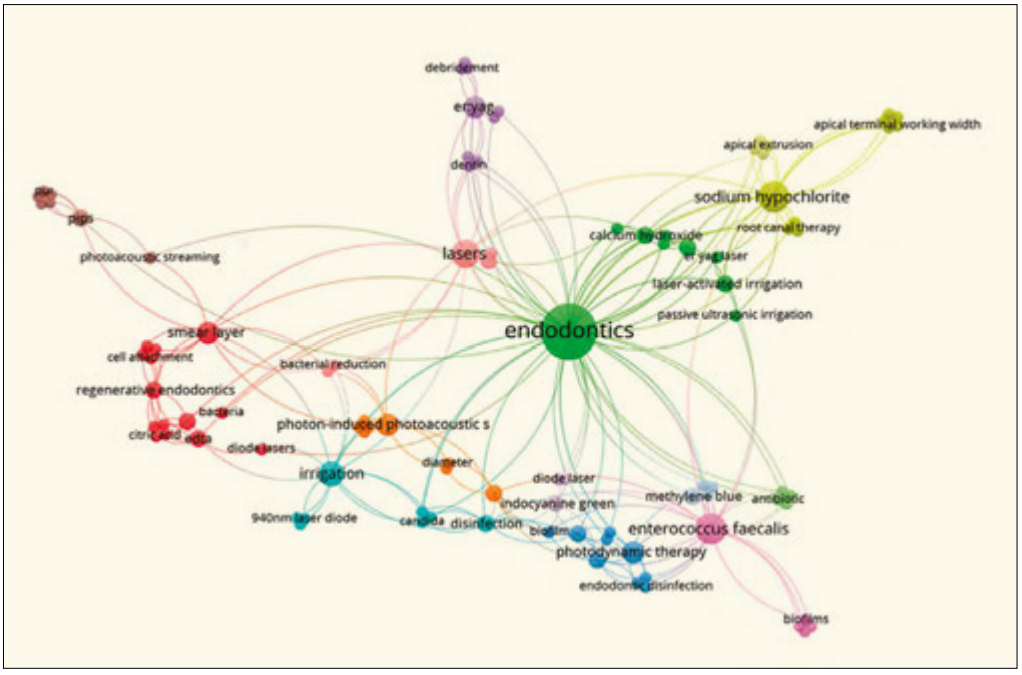
Figure 2
Contribution to the literature based on countries and bibliographic coupling.

Figure 3
Distribution by the journal which published the maximum count of the article.



of particles transported in the fluid stream with 632.8 nm wavelength helium-neon laser or semiconductor diode laser at wavelengths of 780 and 780-820 nm (22, 23). Melcer et al. (1987), proposed a CO_2 laser to provide hemostasis in exposed canine teeth. Besides, Moritz et al. (1998) reported that the CO2 laser used in the application of direct pulp capping of human teeth gives useful results (24, 25). Since then, the Er: YAG laser has gained increasing popularity among clinicians for direct pulp capping application, and it was shown that dentin bridge formation is detected and

Figure 4
Research focuses according to the keywords.



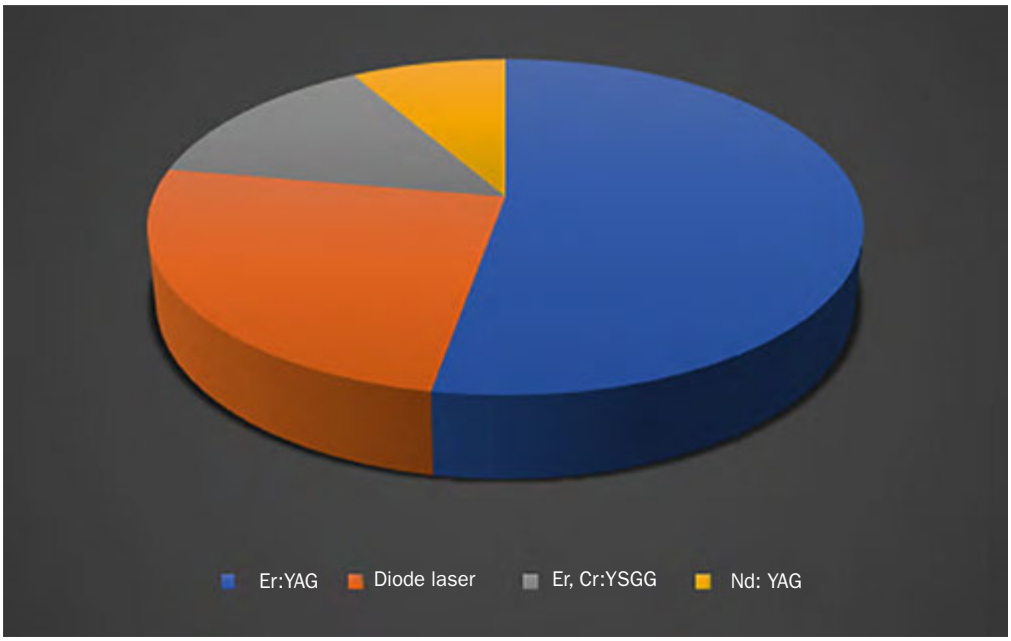


Figure 5
Distribution of laser types used in studies.

doesn't cause any side effects on the pulp (26, 27). In addition, the use of lasers has been introduced to provide a plug in the apical region to prevent leakage. For this reason, various types of lasers were used, especially firstly CO_2 laser in 1971 by Weichman and Johnson (28). In terms of smear layer removal, Er: YAG laser was found to be the most superior among other types of lasers such as Nd: YAG, Argon, and CO_2 (29, 30). CO_2 laser (10.600 nm), Nd: YAG laser (1064 nm), Er: YAG laser (2940 nm), and diode laser (810 nm or 980 nm) Er, Cr: YSGG laser, Ho: YAG laser (2100 nm, 2W,5Hz) have been used for disinfection of root canal system (31-34). However, recent studies have focused on irrigation solution activation, rather than just the use of lasers for disinfection of the root canal system.

66,6% of the articles in the last 5 years included Er: YAG laser in their study design. Er: YAG laser was used in 8 out of 9 total articles published in 2021. Er: YAG laser has a wavelength of 2940 nm, which can be well absorbed in the hydroxyl groups of hydroxyapatites, and water is best absorbed. This provides good interaction with biological tissues, including enamel and dentin, and allows the use of Er: YAG laser in endodontics for different purposes (35). In addition, enabling the use of techniques that can be used for irrigation such as PIPS and SWEEPS may have caused the Er: YAG laser to become widespread in laser studies. It might be speculated that Er: YAG laser use with novel goal-directed techniques is prospective to be the new popular area of interest.

Randomized clinical trials are superior to the other study types in terms of scientific evidence and have a crucial part in evidence-based dentistry. None of the included studies was a randomized clinical trial which indicates the need for further studies for clinical decision-making. The lack of randomized clinical trials might be attributed to the recent introduction of dental lasers to endodontics and the lack of cohort studies and case-controlled studies in the literature (36-38).

The number of articles included in our study might be considered a limitation. The high cost of laser devices, therefore a limited number of research centers and study groups participated in laser research, and the exclusion of case reports and reviews might be the possible reasons. Our study took endodontic laser-activation-related publications into account to highlight the bibliometric characteristics of a highly specific application. Further research might focus on laser application in endodontics in a broader context.

Conclusions

This bibliometric analysis presents an overview of current trends in publications about laser use focused on endodontic irrigation and the determination of prominent journals and countries. The most-cited research articles related to laser use in endodontic irrigation in the last 5 years covered various topics such as bactericidal effect, smear layer removal, pushout bond strength, growth factor release, and apical extrusion of irrigant. 2017 was the year with the highest number of publications, and Türkiye was the highest number of publications on the topic. The highest number of publications were published in Photomedicine and Laser Surgery. Er: YAG laser was the most studied laser in endodontics in the last 5 years.

Clinical Relevance

Laser use in the clinical practice of endodontics has received broad acceptance amongst clinicians. This study provides an overview of current trends in publications about laser use focused on endodontic irrigation and the determination of prominent journals and countries.

Conflicts of Interest

No potential conflict of interest relevant to this article was reported.

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None.

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ORIGINAL ARTICLE

Comparison of antibacterial activity of diode laser 980 nm and double antibiotic paste during regenerative endodontic therapy of mature necrotic teeth

ABSTRACT

Aim: *This study compared the antibacterial effect of diode laser and double antibiotic paste (DAP) on the response of mature teeth with necrotic pulp and apical periodontitis to regenerative endodontic therapy (RET) in a dog model.*

Methodology: *Pulp necrosis and periapical pathosis were induced in 30 mature double rooted premolars in three mongrel dogs aged between 2 to 3 years. These teeth were classified according to the method of root disinfection into three equal groups (10 teeth each), group I: DAP; group II: diode laser (DL) 980 nm and group III: without disinfection (control). Bacterial samples were collected before and after one month of disinfection. The colony forming unit (CFU) and percent of reduction in colony count (%RCC) were evaluated. Revascularization techniques were performed using induction of bleeding and platelet rich fibrin (PRF). The pulp chamber was sealed with mineral trioxide aggregate (MTA) and the coronal cavities were filled with glass ionomer cement. Statistical analysis was done utilizing ANOVA, Tukey's post hoc and paired t tests.*

Results: *The highest mean value of CFU was recorded in the control group followed by group I and group II. The difference in CFU between before and after treatment within each group was statistically significant (P≤0.05). Group II showed the highest %RCC, followed by group I, while the control group showed a percent increase. Percentage of RCC was statistically significant between all groups (P≤0.05).*

Conclusion: *Diode laser 980 nm exhibited more antibacterial effect than double antibiotic paste during regenerative endodontic therapy of mature necrotic teeth in a dog model.*

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KEYWORDS *Diode laser, double antibiotic paste, periapical pathosis, regenerative endodontic, revascularization*

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Introduction

Regenerative dentistry has growing and promising role in the management of endodontic and periodontal lesions. It aims to stimulate the renewal and regeneration of damaged structures like the root, dentin structures and dental pulp complex cells (1). The RET was first suggested for the management of immature teeth with necrotic pulp (2-9).

Recently, regenerative endodontic treatment also shows promising results in mature teeth (10, 11). The idea of pulp regeneration provides biological seal rather than mechanical seal obtained by artificial obturating materials. The subsequent healing reaction to regenerative endodontic in the apical third of the root canal had better resistance to infection (2).

A major prerequisite to achieve RET is to achieve efficient root canal disinfection (8,10). Sodium hypochlorite, mechanical preparation and calcium hydroxide were traditionally advocated for root canal disinfection; however in situations involving biofilm-related infection, they were ineffective (12). As a result, further intracanal medications were suggested as substitutes or adjuncts in root canal disinfection such as triple antibiotic paste (TAP).

One of the main disadvantages of TAP is discoloration of young mature teeth due to minocycline that is one of the components of TAP, consequently double antibiotic paste (DAP) was proposed (12,13). Higher concentrations of DAP eliminate microbes but it has cytotoxic effect on viability of stem cells. DAP with lower concentration (0.1 mg/ml) has a significant effect on bacteria and negative effect on viability of stem cells (13).

Recently the use of laser power has gained an increased interest in the endodontic field due to its bactericidal effect, bio-stimulation, improving the success and longevity utilizing the thermal effect of laser on surrounding tissues (14, 15). This may lead to save the patients from the invasive surgical intervention, so it will save both the patient and the dentist time. The range of laser wavelengths for dental applications ranges between 800 and 1,064 nm (16). A recent study assessed the effectiveness of diode laser in maturogenesis of immature teeth with necrotic pulps and endorsed using it (17). However, there are few studies on the antibacterial effect of diode laser in regenerative endodontic. This section of the research compared the antibacterial effect of diode laser and DAP on the response of mature teeth with necrotic pulp and apical periodontitis to RET in a dog model.

Materials and Methods

Ethical approval

The research was approved by the Research Ethics Committee at Faculty of Dental Medicine for Girls, Al Azhar University, Egypt (P-EN-21-03). Additionally, all the Animal Research: Reporting of in Vivo Experiments (ARRIVE) guidelines were followed up.

Animal model

Three 2 to 3-year-old mongrel dogs were enrolled in this study. The dogs were obtained commercially from Al-Fahad Trading Company for Animals (Abu Rawash, Giza, Egypt). These dogs were kept in separate cages under optimum conditions of ventilation, cleanliness standards, and a healthy diet in the Department of Veterinary Surgery, Faculty of Veterinary Medicine, Cairo University, Egypt. They had complete set of permanent dentitions and mature teeth with no sex predilection (11). In each dog, 10 premolars were used to sum 30 teeth constituting 60 root canals. These teeth were divided into three groups (10 teeth each). Each group was randomized equally in the upper and lower jaws in each animal (10 teeth: 4 teeth in upper jaw and 6 teeth in lower jaw). The right side included the control and laser groups while the left side included the control and DAP groups.

Sample size calculation

Sample size calculation was done using alpha (α) level of 0.05 (power = 80%) by IBM® SPSS® Sample Power® Release 3.0.1.

The calculation was estimated using CDC Epi Info program version 7.2.0.1 (Atlanta, USA). A total sample of a minimum 28 teeth from two dogs (10 each experimental group; and 8 for the control group) was needed based on an estimated mean bacterial count of 1.712±0.848 in experimental group using diode laser compared to 0.552±0.097 in experimental group using double antibiotic paste (17).

Classification of samples
Thirty mature premolars were divided into two major experimental groups and one control group (10 teeth each) according to the disinfection protocol; Group I: Double antibiotic paste, Group II: Diode laser 980 nm and control group that represented teeth with induced infection and without treatment.

Induction of periapical pathosis
General anesthesia was administrated after fasting the dogs for 12 hours. The dogs were premedicated by 0.05 mg/kg body weight atropine sulphate (Atropine sulphate 1%®, ADWIA, Egypt) injected subcutaneously and 1 mg/kg weight xylazine HCl (Xylaject 2%®, ADWIA, Egypt) injected intramuscularly. The anesthesia was induced by using ketamine HCl (Ketamine hydrochloride®, Rotexmedica Co., Germany) injected intravenously through a cannula in the cephalic vein at a dose of 5 mg/kg body weight. The anesthesia was maintained by 2.5% thiopental sodium (Thiopental sodium®; EIPICO, Egypt) at a dose of 25 mg/kg body weight solution injected intravenously. Coronal cavity was made in all experimental and control teeth. Exposing the pulp chamber was made using #2 diamond stone with high-speed handpiece mounted on a portable unit. A sterile file #15 was used to disrupt the pulp. Supra gingival plaque from the dog's teeth was mixed with sterile saline solution; sterile sponge was soaked in the plaque suspension and inserted into the pulp chamber. A piece of cotton was put into the entrance of each canal, and the coronal cavities were filled by cotton for one month. Dogs were given soft diet and Carprofen tablet (Rimadyl tablet®, Zoetis, USA) orally for 10 days at a dose of 4.4 mg/kg once daily as postoperative analgesia (5-8).

Preparation of double antibiotic paste
To prepare diluted concentration of DAP, equal portions of ciprofloxacin (Ciprocin 250 mg Capsule®, EIPICO, Egypt) and metronidazole (Flagyl 250 mg Tab®, Sanofi Aventis, Egypt) were mixed with distilled water to obtain a concentration of 0.1mg/mL, then, 2.5 g of methyl cellulose powder was added to 100 mL of DAP with concentration (0.1 mg/mL) under magnetic stirring to achieve a homogenous gel that was used in this study (18).

Pretreatment bacterial samples and colony-forming units (CFU /mL)
Under the same general regimen of anesthetics, proper aseptic conditions and rubber dam isolation, the previously infected experimental teeth were entered again. The soaked cotton was pulled and each root canal was filled with sterile saline solution as a transport fluid. Bacterial samples were taken by introducing 4 sequential absorbent paper points of size compatible with root canal diameter up to the working length, which was delimited 1 mm from the radiographic apex. After 30 seconds, the paper points were removed from the canals and placed in a sterile test tube containing 2 mL of sterile saline. One mL of water was quantitatively cultured (using 100 and 10-1 dilutions) on Mueller Hinton culture media. After the incubation period, the developed colonies of bacteria were counted and the number of colony-forming units per mL (CFU/mL) was determined. The CFU/mL value was calculated using the following formula: CFU/mL=average number of colonies × inverse of dilution (19).

Root canal preparation and disinfection
After the infection period and under general anesthesia, periapical lesions had been verified by periapical radiographs. All previously infected teeth were accessed again under aseptic conditions and rubber dam isolation. The working length to the anatomical apex was determined for REP

using an apex locator (E- CONNECT, E-PEX Pro, Eighteeth, China). The root canals were instrumented to the desired length using ProTaper Universal system (Dentsply Maillefer, Ballaigues, Switzerland) up to #F4. All canals were irrigated using 2 mL of 1.5% sodium hypochlorite (NaOCl) between each file (Clorox Co., Egypt) with a 27-gauge side vented needle during all steps of preparation. Canals were rinsed finally with 0.9% normal saline (20 mL/canal, 5 min), dried with paper points and dressed with DAP in group I. The DAP mixture was put intra canals by injecting through the canal using a 20-gauge sterile plastic syringe. The access cavities were filled with the glass ionomer as a temporary filling material and teeth were left for one month before the second intervention.
On the other hand, disinfection by diode laser in group II was held after mechanical preparation. The root canals were filled with 2 mL of 1.5% sodium hypochlorite, the laser fiber (980 nm, 2.5w) was entered inside the canal 1 mm before apex and, then the fiber was moved up and down inside the canal to perform lasing.
The root canals were dried, and then the laser fiber tip (980 nm, 2.5w) was reinserted 1 mm shorter than the actual working length. The fiber was moved in a circular motion from the apex to the coronal end and from the coronal end to the apex (5 passes with 5 seconds in-between where the pass was from the apex to the coronal end). The internal wall of the canal wasn't touched with the fiber tip (20).
The coronal cavities were filled using glass ionomer restoration (Riva Self Cure, SDI Limited, Australia).

Treatment modalities
After one month and under the same general anesthesia as well as aseptic techniques, the experimental teeth were entered again, the glass ionomer restoration was removed using diamond stone. The root canals were treated according to different treatment protocols for experimental groups as follows.
In group I, DAP was removed with copious irrigation with distilled water followed by 6mL of 1.5% NaOCl solution and 17% EDTA solution (Prevest Denpro, Digiana, Jammu, India) (5 mL/canal, 5 min). Distilled water with paper point dryness was used in between irrigations.
In group II, the canal was irrigated with 2 mL of 1.5% NaOCl solution, then activated by diode laser 980 nm at power of 1.5Watt with Ton=10milliseconds; T off=10milliseconds 50Hz (50% pulse mode). The fiber optic tip with size 200 micron diameter was applied intra the canal 1 mm short of the working length moved in helical movement along the root walls at speed of 2mm/sec. Distilled water with paper point dryness was used in between irrigation. Irrigation with 17% EDTA solution and irradiation with the laser were performed and followed again by 2mL of 1.5% NaOCl irrigation. Final irrigation with EDTA 17% solution for 1 minute was carried out and followed by final rinse with distilled water and paper point dryness (21).

Post treatment bacterial samples and bacterial count
When root canal disinfection procedure was done, post treatment bacterial samples and count were performed by the previously described method. The root canals were then dried with sterile paper points for regeneration protocol.
For bacterial count, visible colonies produced before and after treatment were counted in every plate. The number of colonies/plates was multiplied by the corresponding dilution factor and by 10 to determine the total colony forming units (CFU) per mL of sample. Antibacterial effectiveness was assessed by determining the percentage of reduction in colony counts (%RCC) before and after treatment (8).
Calculation of the change's percentage as:

$$\frac{\text{(CFU base line(befor treatment)-CFU a month (after treatment)}}{\text{(CFU baseline (befor treatment))}} \times 100$$

Procedure of pulp regeneration
A sterile size #20 hand K-file was inserted 2 mm beyond the canal terminus until bleeding was induced to fill the canal space. The blood clot was formed at several minutes. A total of 20 mL venous blood

was taken from the dog's cephalic vein. The blood sample was put into a test tube without anti-coagulant and centrifuged immediately using a tabletop centrifuge (REMI Laboratories, Mumbai, India) at 3,000 revolutions per minute for 10 minutes. Three separate layers were formed in the tube: platelet-poor plasma at the top, platelet-rich fibrin clot (PRF) at the middle and red blood cells at the bottom. Sterile instrument was used to gently remove the PRF clot. Sterile dry gauze was used to squeeze the PRF clot. Cut pieces of the freshly constructed PRF membrane were added incrementally in the canal using a finger plugger up to the level of the cemento-enamel junction (CEJ). Orifices were plugged using MTA, and the coronal cavities were sealed by glass ionomer filling (6).

Statistical analysis
Data management and statistical analysis were performed using the Statistical Package for Social Sciences (SPSS) version 18. The summaries of numerical information used mean, standard deviation and confidence intervals. Data were explored for normality by checking the data distribution and using Kolmogorov-Smirnov and Shapiro-Wilk tests. Comparisons between groups with respect to normally distributed numeric variables were done by one-way analysis of variance (ANOVA) test, followed by Tukey's post hoc test. Comparison of total bacterial count within the same group was performed by paired t test. All P-values were two-sided. P-value ≤0.05 was considered significant.

Results

Comparison of total bacterial count between groups
The data are collected in table (1). Before treatment, the highest mean value was recorded in group II (Diode laser), followed by group I (DAP), while the least value was recorded in control group. The difference between groups was statistically significant (P≤0.05). Tukey's post hoc test revealed no significant difference between group I and group II.

After treatment, the highest mean value was recorded in control group, followed by group I (DAP), while the least value was recorded in group II (Diode laser). The difference between groups was non-statistically significant (P 0.05).

Comparison of total bacterial count within the same group
The data are shown in (Table 1). The difference between before and after treatment was statistically significant in all groups (P≤0.05).

Percentage of reduction in colony count
The data are shown in (Table 2). Group II (DL) showed the greatest percent decrease and followed by group I (DAP), while the control group showed a percent increase. The difference between all groups was statistically significant (P≤0.05).

Discussion

Endodontic therapy is a time-consuming procedure. It involves multiple visits, high fees and fracture risk. RET of necrotic mature teeth could face these drawbacks because it induces a biological obturation of the root canal in the form of newly developed tissues ingrowth (10, 11).
One of the main and crucial steps for successful RET is the disinfection of the root canal. So, this study compared the antibacterial effectiveness of DL and DAP as intra-canal disinfectants. This experiment proved that DL has better antibacterial effectiveness than DAP for disinfection of the root canal during RET of necrotic mature teeth in a dog model. Moreover, the DAP's known drawbacks as development of the bacterial resistance can be excluded by using diode laser for disinfection in regenerative endodontic.
In the present study, dogs were chosen as an animal model because dogs have similar apical repair compared with humans in shorter time (average one sixth of human) due to increased growing rate (5). The double rooted premolars were chosen to sum up 10 teeth in each dog with 20 root canals in order to increase the whole number of samples for a reliable statistical

Table 1

The mean Log_{10}, standard deviation (SD) for comparison between Log_{10} CFU of bacterial counts in all groups before and after treatment

Groups		Mean	SD	Difference				t	P
				Mean	SD	C.I. Lower	C.I. upper		
Group I (DAP)	Before	4.40[a]	.787	.85	.06	.82	.88	56.91	.000*
	After	3.549	.797						
Group II (DL)	Before	4.60[a]	.946	1.35	1.07	.73	1.97	4.73	.000*
	After	3.254	.739						
Control group	Before	3.55[b]	.073	-.04	.01	-.05	-.03	-14.38	.000*
	After	3.585	.079						

**Significance at P≤0.05. C.I=95% confidence interval. Tukey's post hoc test: sharing the same superscript letter are not significantly different.*

Table 2

Comparison between groups regarding percentage of reduction in the number of colony forming units (%) of microorganisms

Groups	Mean	SD	95% Confidence Interval for Mean		Min	Max	F	P
			Lower Bound	Upper Bound				
Group I (DAP)	-85.74[b]	1.82	-86.79	-84.69	-88.00	-81.75	7287.393	.000*
Group II (DL)	-92.77[c]	2.59	-94.27	-91.27	-95.77	-86.86		
Control group	9.40[a]	2.17	7.85	10.95	7.00	13.00		

**Significant at P≤0.05. Tukey's post hoc test: with different superscript letters are significantly different.*

analysis. Additionally, premolars are available for endodontic treatment and have appropriate-sized canals (5, 6, 8).

The choice of 1.5% NaOCl solution as an irrigant in this study is due to its potent antimicrobial action, preservation of stem cells and growth factor release that are necessary in RET (22). Also, using of 17% EDTA solution for conditioning was based upon its demineralizing effect on the superficial dentin layer with release of growth factors and removal of loosely attached smear layer (4, 10, 23).

Because of its convex triangular cross-section, ProTaper Universal rotary files were used to instrument canals because they reduced friction between the blade and the canal wall and improved cutting efficiency. Additionally, their design facilitates cutting, enables the blades to clear debris from the canal, and avoids accidental screwing into the canal. To guarantee that the root canals were completely cleaned and shaped, the apical preparation of the canals was finished with an F4 ProTaper Universal file (24).

Because 1 mg/mL DAP in a prior trial did not demonstrate significant changes in direct antibacterial activity (10), 0.1 mg/mL DAP for one month was preferred in the current study. Additionally, DAP at this lower concentrations has a consid-

erable impact on microorganisms and a detrimental impact on stem cell survival (13). Nevertheless, DAP at low concentrations (0.1 mg/mL) makes its use hard therefore; methyl cellulose was employed as a vehicle in order to achieve a consistency suitable for clinical use and to lengthen the duration of the therapeutic agent. Previously, the intracanal medications have been delivered using methyl cellulose, a synthetic polymer of cellulose (18, 25). Regarding the disinfection period (one month), previous study concluded that dentin pretreatment with 5 mg/mL of DAP or higher for a month induced significantly higher residual antibiofilm effects in comparison to one-week pretreatment with the same concentrations (1).

Due to its three-dimensional architecture, autologous nature, and bioactive compounds that promote regeneration (7, 26), PRF was utilized in this investigation to display the multipotent stem cell (MSC) markers and to show significant mineralizing differentiation potential. The MTA was applied to the blood clot due to its biocompatibility and superior mechanical and sealing qualities, it is the drug of choice for scaffold covering in RET (2, 7, 27).

To avoid reinfection inside the canals that could impair the outcome, final coronal restoration was completed following endodontic therapy. According to reports, coronal leakage is a factor in root canal therapy failure, and success rates are higher for teeth with high-quality restorations than for teeth with poor restorations (28).

In this study, diode laser was used as it is effective in reducing intra canal bacterial count and penetration in the depth of 500 microns in dentin. Compared to other kinds of lasers, it is smaller and significantly less expensive (20).

In the current work, intracanal irradiation was carried out in a pulsed mode to reduce the possibility of thermal harm to the underlying bone, periodontal tissues, or external root surface, which decreases the postoperative pain and promotes periapical healing. As previously noted, a diode laser evenly spreads the beam throughout the root canals to ensure a successful photoreaction (14, 15). In a recent *in vitro* investigation, using optical fiber to disinfect the root canal led to a greater antibacterial impact (29). While a different in vitro investigation found a reduced antibacterial impact, this could be explained by the varied experimental methodologies (30). Similarly to the results of the present study, diode laser 980 nm could reduce the bacterial infection up to 88.38% with a distal output of 0.6 watts in continuous wave (CW) mode. A 980 nm diode laser induced antibacterial effect in root canals infected with *Enterococcus faecalis* at 77 to 97% (31). Lasers are used in wet canals to worm the irrigating solution and increase its disinfectant capacity. To make sure the laser covered the whole internal wall of the canal, the fiber was moved in a circular motion from the apex to the coronal end and back again. Touching the internal canal wall with the fiber tip was avoided to avoid melting the dentin and transferring the thermal impact to the area around the periodontal ligaments. Additionally, the fiber tip was maintained clean to produce an effective laser beam (20).

While microbiological sample (S2) was taken after laser application using paper points as in (S1) but after scrubbing the canal wall with the master apical file to detach microorganisms attached to the canal wall, microbiological sample (S1) was taken after irrigation of the root canals with 1 mL saline to allow adequate collection of microorganisms on the paper point. The similar idea was applied to a study that separated the surface biofilm before cultivating in order to prevent misleading negative results (32).

Removal of cultivable microorganisms remains the major goal and can be utilized as a surrogate outcome of the clinical studies, whereas the microbiological reduction following root canal cleaning is regarded as an immediate outcome. Therefore, the microbiological analysis of the samples was used for this study in order to assess the reduction in the number of CFU of microorganisms. The difference in CFU at baseline was taken into account because this discrepancy could lead to errors in over- or underestimating the differences between the two groups (33).

Regarding diode laser group, the result of this study is in agreement with a previous study that compared the antibacterial effect of diode laser 980 nm and triple antibiotic paste and concluded that diode laser could be used instead of triple antibiotic paste for disinfection of root canals in revascularization (17).
Regarding DAP group, the result of this study is in agreement with a prior study that looked at the impact of several dilutions (0.125, 0.25, 0.5, 1, and 10 mg/mL) of antibiotic medicines (DAP and TAP) used in endodontic regeneration to see how they affected the growth of an *Enterococcus faecalis* biofilm. It concluded that *Enterococcus faecalis* was resistant to all tested dilutions' antibacterial effects. However, DAP and TAP at 0.125 mg/mL had a notable antibacterial impact without having cytotoxic effects on stem cells (13).
The decrease in CFU between before and after treatment was statistically significant in groups I and II due to the antibacterial effect of both DAP and diode laser. While the result of control group showed significant increase in the CFU due to the absence of disinfection. These findings support those of a prior investigation (8). In contrast, the rate of RCC in various groups deviates from the findings of other studies (13). This variation could be explained by the employment of various approaches in each study.
Further studies are recommended to compare the antibacterial effect of diode laser 980 nm and 1.5% NaOCl in regeneration, to assess 980 nm diode laser on the disinfection of mature teeth in endodontic regeneration of human teeth, to use 980 nm diode laser on the disinfection of retreated root canals in case of failed root canal treatment, and to evaluate the antibacterial effect of 980 nm diode laser on different microbial endodontic species.

Conclusions

Diode laser 980 nm showed more antibacterial effect than double antibiotic paste during RET of mature teeth with necrotic pulp and periapical pathosis.

Clinical Relevance

Using of diode laser 980 nm induces immediate root canal disinfection during RET of mature teeth with necrotic pulp and periapical pathosis that will save both the patient and the dentist time and allow to make RET in one visit.

Conflict of Interest

There are no conflicts of interest.

Acknowledgments

None

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ORIGINAL ARTICLE

Computational fluid dynamic analysis on the induced apical pressures in simulated oval and irregular round canals: an ex-vivo study

ABSTRACT

Aim: *Fluid dynamics can be understood in-vitro by observing the fluid flow patterns in the simulated canal models. The current study aimed at assessing the apical pressures in simulated oval and irregular round canals using computational fluid dynamic analysis (CFD) as a tool.*

Methodology: *Following the ethical approval, a total of 58 freshly extracted mandibular second premolars were collected for the present study. Cone-beam computed tomography (CBCT) scanning was done to confirm the root canal morphology. Based on the specified inclusion and exclusion criteria, the specimens were divided into two groups: group I: irregular round canals (n=29), and group II: completely oval canals (n=29). Following this, the instrumentation of the specimens was carried out using the XP-Endo Shaper (XPS) file system. A post-instrumentation CBCT was then taken to obtain a computer-aided design (CAD) model. Once the CAD model was obtained the CFD simulations were then carried out at different needle placements.*

Results: *Group I showed significantly higher (P<0.05) apical pressures at all the needle positions analyzed.*

Conclusion: *Oval-shaped canals showed the least apical pressures at all needle positions as compared to irregular round canals.*

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Introduction

Fluid dynamics is a complicated aspect which can only be understood by observing the fluid flow patterns through in-vitro analysis (1). The stresses generated on the root canal walls in due course of irrigation cause the effective smear and the biofilm removal (2, 3). Nevertheless, these stresses should never cross the physiological limit (1). The direction of the irrigant flow in the apical portion and the irrigant interaction with the canal walls depends on the nature of the delivery system used (4). As the fluid flow occurs in the root canal, there are wall shear stresses (2) and turbulent forces which are generated in the root canal system (5). So, clinically these increased forces generated tend to cause irrigant extrusions if the irrigant pressure exceeds apically (6). Especially the pressures generated tend to be higher with the usage of positive pressure irrigation systems (7, 8). However, a clinician should always maintain a subtle balance in maintaining both safety and efficacy during the irrigation with the positive pressure delivery systems (9).
Although it's effective to achieve enough fluid exchange by placing the irrigation needle close to the estimated working length, it's equally important to control the irrigant flow within the confines of the complicated root canal system (9). Studies claim the increased positive pressures in canals when the fluid flow rate increases (7, 10-13). Usually, these increased pressures cause irrigant extrusions clinically, when the flowing fluid pressure exceeds 30 mm Hg, which approximates the intraosseous blood pressure (9). Among the used positive pressure delivery systems, closed-ended side vented needles are claimed to be effective in inducing higher shear wall stress, with lower generated apical pressures (8, 14). and least extrusions (15). Current systematic review evidence based on computational fluid dynamic analysis (CFD) also showed the improvement in the irrigant flow parameters with reduced apical pressures, when a 30 gauge side vented was simulated during the laboratory irrigation (1). Among the different fluid flow rates investigated in-vitro using various non-binding needles, flow rates greater than 3-4m/min was claimed to cause excessive apical pressures (16). However, a practising clinician can never maintain a standard irrigant flow rate while using positive pressure syringe needle irrigation (17). There are various factors like the operator-based factors (10), the curvature of the tooth (18), choice of needle type and design (19), taper (20) and preparation sizes chosen (21), which play a vital role clinically in altering the irrigant flow rates. However, most often the extrusions tend to happen clinically when the needles are wedged into the root canal (22).
Among the various investigated needle types, closed-ended side vented needles are claimed to be the safest for clinical use (23). So in the current study, we have carried out all the evaluations with a simulated side vented closed-ended needle. As far as the previous literature is concerned such on root canal morphologies, to our knowledge, there are only two studies (8, 24), which assessed the apical pressures in simulated oval (8) and c-shaped canals (24). However, there are no focussed studies as such to date assessing the apical pressures in oval and irregular round canals, which are most frequently encountered clinically with mandibular premolars (25). Considering all these facts, the current study aimed at assessing the apical pressures in simulated oval and irregular round canals using CFD as a tool.

Materials and methods

Institutional human ethical committee approval was obtained from the university (SRB/SDC/ENDO-2102/21/030) before the research has begun. The recent PRILE guidelines were followed for conducting the current study (26). Sample size estimation was carried out based on previous research by our colleagues (27). A total sample of 58 was achieved at a power of 95% and an effect size of 0.97 (1-β=95%, α=0.05).
Before the extraction, informed consent

was obtained from the patients. A total of 58 freshly extracted mandibular second premolars were collected for the current study. The entire specimen collection process was carried out by a postgraduate (S), who was not involved in the study. Extracted teeth due to periodontal or orthodontic reasons, teeth with minimal curvatures <5 degrees, and teeth with intact apices were selected for the current study. Carious teeth and teeth with canal calcifications and resorption were excluded from the current study. Extracted specimens were immediately stored in phosphate-buffered saline solution (P10400-1000.0 - PBS 1X Solution) after curettage of the soft tissue debris from the extracted surface. After the storage of 24 hrs, the specimens were evaluated for a single canal morphology using an intra-oral periapical radiograph (IOPAR).

Following the initial conformation, the specimens were then subjected to cone-beam computed tomography (CBCT) to confirm the specified root canal morphologies. A Kodak 9000 device (Carestream Dental Kodak Systems, Rochester, NY) was used for the scanning of the collected specimens. The scanning was carried out at 70 kVp, 6.3 mA and a resolution of 0.76 mm. The scan time was around 10.8 seconds and at a FOV of 18.4cm x 20.6 cm. After subjecting to the CBCT, the specimens having either irregular round or completely oval canals were only considered for the study. The entire evaluation process was done by a radiologist (P) having more than 5 years of experience. Once the specimens were confirmed, they were decoronated using a diamond disc under adequate coolant to standardize the root length to 12 mm and the working length (WL) determination was carried out. The entire specimen collection, decoronation and WL determination were carried out by the same postgraduate (S) who was not involved in the study.

The specimens were then randomly divided into two groups based on the canal morphology as the group I: irregular round canals (n=29), and group II: completely oval canals (n=29). Following this, the specimens were provided to an operator (SC) who was blinded to the entire experimentation protocol. The instructions on the chemo-mechanical debridement were provided to the operator (SC) by a supervisor (KVT). The initial patency was achieved using an ISO No #10 K- hand file (Dentsply Maillefer, Ballaigues, Switzerland). Following this, the instrumentation was carried out using an XP-Endo Shaper (XPS) file system (XPS; FKG Dentaire SA, La Chaux-de-Fonds, Switzerland). Pecking motions were carried out for the instrumentation until the desired WL was reached. Debris accumulated on the instrument was cleaned after every three pecking motions using an alcohol swab. After each instrumentation, the files were immersed in the temperature-controlled water bath (35±1.0 °C) to maintain the XP phase of the system.(28) After the complete shaping, the final rinse was carried out using 4 ml of 5.25% sodium hypochlorite (NaOCL) (Parcan, Septodont, France) and 5ml of 17% ethylene diamine tetra-acetic acid solution (EDTA) (MD Cleanser, MetaBiomed, South Korea). The final flush was carried out using 5ml of distilled water. A total of 20 ml of 5.25% NaOCL was standardized for each specimen during the entire protocol. The entire irrigation was carried out using a 30 gauge single-side vented needle (NaviTip, Ultradent Products, South Jordan, UT, USA) attached to a 5ml syringe barrel. Following the instrumentation, the specimens were subjected to CBCT analysis. A total of five-hundred sections were analysed in Galileos Viewer Software to recreate a three-dimensional computer-aided design (CAD). The DICOM file of the isolated root canal was converted to an STL file format using Mimics Medical 2.0 software. The STL file was then converted to a Parasolid file for analysis using Space Claim 2021 R2 software. Following this, the real geometry of the 30 gauge side vented needle was recreated (Dext=320 µm, Dint=196 µm, l=31 mm). Gambit 2.4 (Fluent Inc., Lebanon, NH) was used for hexahedral mesh reconstruction. Grid refinement and the grid independency check were done to ensure computational resource usage. A final mesh was then obtained depending on the canal

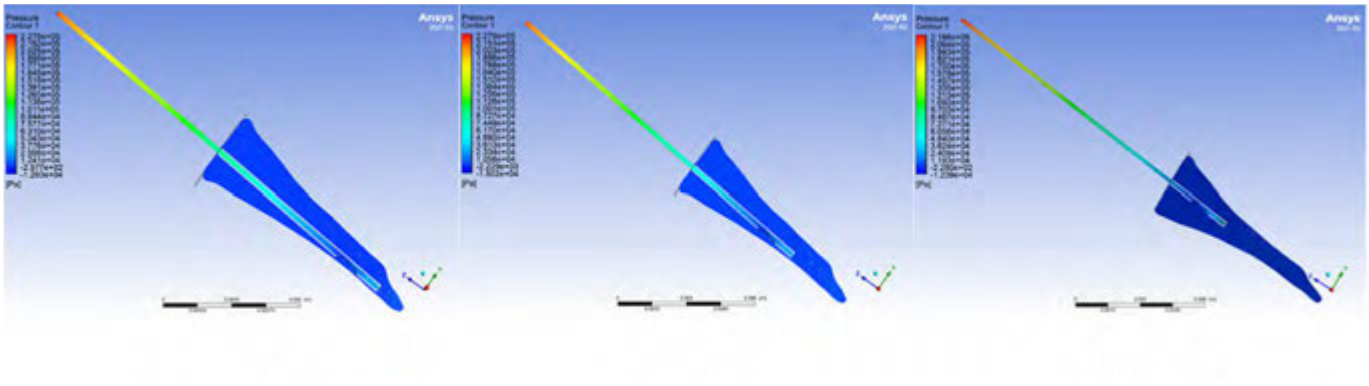

Figure 1
Depicting the simulation carried out at different needle positions in irregular round canals.

shape (mean cell volume 0.7–2.1×10–5 mm^3).
CFD simulations were then carried out using Ansys Fluent 2012 R2 software (Figure 1, Figure 2). The simulations were carried out at a constant volumetric flow rate of 0.26 mL/s by placing the needle at 25%, 50%, and 75% short of the working length (WL). A flow rate of 0.26 mL/s correlates to the laminar flow at a flow velocity of 8.99 m/s and with a Reynolds number of 1678. A shear stress transport (SST) k-ω model was then used for the turbulent flow analysis. Liquid viscosity was considered by reinforcing no slip conditions on the needle and the root canal walls. Gravity was considered in the direction of the flow (i.e., -z-axis). The mean value of four simulations was taken into account for the final analysis.

Statistical analysis
Data analysis was done using IBM SPSS Statistics Software for Windows Version 23.0 (Armonk, NY, USA, IBM Corp). The apical pressures in different groups were compared using an Independent T-test.

Results

The current study results showed significantly ($p<0.05$) higher apical pressures in group I (Table I) as compared to group II at all the needle positions analyzed (25%, 50%, 75% short of WL).

Discussion

The present study results showed a significant difference ($p<0.05$) in the recorded pressures at all needle positions in different groups analysed. Among the oval and irregular round canals compared, the mean pressure values were significantly higher ($P<0.05$) in irregular round canals as compared to the completely oval canals. To date, there is no specific literature as such comparing the apical pressures in single irregular round canals as compared to the completely oval ones. However, the previous studies state that, as the space between the positioning needle and the root canal walls increases, the pressures elicited tend to decrease (21). Hence, in the current study, the oval canals recorded lower pressures at all the needle positions. To our knowledge, there is only one study which assessed the pressures during root canal irrigation in single and anastomosed poly-carbonate models (9). The study results showed a similar outcome, where the recorded pressures were significantly higher with the single canal models (9). When the different needle positions were assessed, the recorded pressures were higher when the needle position was 25% short of WL. Previous studies were also in correlation with the current study which showed higher recorded pressures when the needle placement was more apical (27, 29). From this, it can be inferred that the pressures are more related to the needle placement than the type of canal morphology.
When the literature as such on root canal anatomy is concerned, one study has assessed the pressures in different facing of side vented needles in c-shaped canals (24), which is not in relevance to the present study rationale. The other study which assessed the positive pressure irrigation

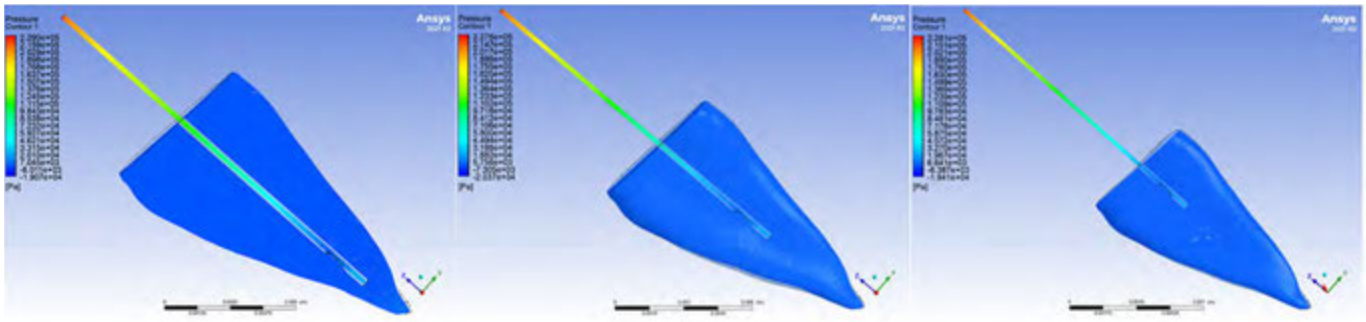

Figure 2
Depicting the simulation carried out at different needle positions in completely oval canals.

in oval-shaped canals confirmed lesser pressures with higher shear stress when a simulated side vented needle was used for the irrigation (8). To our knowledge to date, there is no focused research which evaluated the apical pressures in different canal morphologies. In the present study, we have simulated a similar flow rate of 0.26 ml/s which is claimed to be the highest possible flow rate clinically on using syringe needle irrigation (30). In vitro-based CFD studies also employed similar flow rates (31). Hence, we employed above mentioned flow in our current study. When the current study results were critically assessed, the entire protocol of instrumentation and irrigation was performed by a single operator who was blinded to the study design. The instrumentation was carried out using an XPS file system as it is effective in debriding the oval-shaped canals (32, 33). As far as the irrigation regimen is concerned, we have standardized the irrigant type, volume and concentration in both the groups. So the possibility of experimentation-related bias is avoided. The reason for choosing the irregular round canals was because it's quite unusual to find the complete round canals clinically (27). So, to simulate the most possible clinical condition, the extracted second premolars with completely oval and irregular round canals were only considered for the current study.
The current study's limitations were not considering the flow rate assessments with different possible flow simulations. In the current study, we employed a stationary needle placement during the entire simulation. But previous literature states the better flow and least pressure when the needle was oscillated continuously (34). So, future studies can better concentrate on assessments of different canal anato-

Table 1
Table presenting the pressures elicited in different groups at various needle positions assessed

Table depicting the pressures elicited in different groups at various needle positions						
Needle position	**Groups**	**N**	**Mean**	**Std. Deviation**	**Std. Error Mean**	**P-Value**
25% WL	Group I	29	11714.2418	1016.11732	188.68825	.001
	Group II	29	5100.2242	493.93498	91.72142	
50% WL	Group I	29	3244.2222	266.98782	49.57839	.004
	Group II	29	1012.5389	124.13089	23.05053	
75% WL	Group I	29	2107.3750	325.73380	60.48725	.000
	Group II	29	642.5249	79.97808	14.85156	

25% WL- 25% short of the working length; 50% WL- 50% short of the working length; 75% WL- 75% short of the working length.

mies at varied flow rates and needle placements. Future studies can also assess the simulated biofilm removal and shear stresses caused by different irrigation needles in varied canal anatomies.

Conclusion

Oval-shaped canals showed the least apical pressures at all needle positions as compared to irregular round canals. When different needle positions were compared, the recorded pressures were higher when the needle was placed 25% short of the WL.

Clinical relevance

Apical pressure generated in root canals during irrigation, clinically cause the extrusions. The literature is also scarce on the generated apical pressures in different canal morphologies. In the present study, we assessed the apical pressures produced in simulated irregular round and completely oval canals at different needle positions using CFD. The present study results showed significantly higher apical pressures at all needle positions.

Conflicts of Interest

No conflicts of interest.

Acknowledgements

I affirm that I/we have no financial affiliation.

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CASE REPORT

Controlled drug delivery system endodontic paste as intracanal medication: a bench-to-chair-side case report

ABSTRACT

Aim: *To report a new endodontic paste as intracanal medication in an immature tooth with acute periradicular abscess.*

Summary: *A 9-year-old male child presented to the School of Dentistry with spontaneous moderate pain and swelling in the left permanent mandibular first molar region. Radiographic and intraoral clinical exams revealed previous endodontic treatment with an extensive radiolucent area and incomplete rhizogenesis. The clinical diagnosis was acute periradicular abscess, leading to retreatment. After desobturation and chemical-mechanical preparation, the paste composed of tricalcium phosphate, calcium tungstate, amoxicillin microspheres, and indomethacin nanocapsules was inserted into the root canal system. After 5 months, there were no patient-related symptoms, and an apical barrier has formed with decreased periradicular radiolucent area was observed. The root canal filling and tooth restoration were conducted. At the 1st follow-up - 6 months later - the patient remained symptoms free, and the bone density was still increasing. At the one-year follow-up, there were no clinical symptoms, and a regression of the radiographic lesion with a zone of a hard tissue-like spicules aspect at the external tooth surface could be observed. The case's positive outcome reported a proof-of-concept of the new endodontic paste at the apexification clinical situation.*

Key Learning Points:

- *The present case report showed promising healing results of an experimental material at a molar apexification.*
- *The first clinical study that evaluated an endodontic paste with controlled drug delivery systems as an intracanal medicament.*
- *The controlled drug delivery of amoxicillin microspheres and indomethacin nanocapsules associated with α-TCP favored the healing process and the apical barrier formation.*

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Introduction

Immature permanent teeth diagnosed with pulp necrosis present interrupted root development and incomplete apical closure. In these cases, endodontic treatment becomes a challenge due to the thin and fragile root canal walls and the root apex width (1). Using bioactive materials could promote an apical barrier leading to proliferation and differentiation of cells to achieve the root apexification (2).

Over the years, calcium hydroxide paste has been used as an intracanal medication for mature and immature teeth due to its antimicrobial effects, bioactivity, easy resorption, and absence of foreign body reaction (3). However, it presents some shortcomings like limited anti-inflammatory effect (3), low efficiency in reducing postoperative pain (4), and not user-friendly handling. Moreover, calcium hydroxide paste needs to be changed from time to time until the apical mineralized barrier formation (5). Several new materials have been studied to improve the outcomes of immature permanent teeth treatments. Changes in hydraulic cement's composition, adding different inorganic compounds, antimicrobial agents, and anti-inflammatory drugs are the most studied modifications (6-8).

Materials presenting long-lasting antimicrobial, anti-inflammatory, and bioactive effects with drug delivery systems have

Table 1
Timeline associated with case management

Month/Year	Appts.	Events	Clinical and radiographic characteristics
April/2019	1st	Patient visited School of Dentistry of UFRGS; Dental and medical history; Clinical and radiographic evaluation of tooth #36 (Fig. 2A); Desobturation procedure; Chemical-mechanical preparation; Intracanal endodontic paste insertion (Fig. 2B).	Clinical: spontaneous moderate pain, swelling, positive vertical/horizontal percussion and palpation. Radiographic: unsatisfactory previous endodontic treatment with voids and overfilling, incomplete rhizogenesis and extensive radiolucent area.
September/2019	2nd	Clinical and radiographic evaluation (Fig. 2C); Root canal filling (Fig. 2D); Tooth restoration.	Clinical: symptoms free, apical barrier formation. Radiographic: increase of bone density.
April/2020	1st follow-up	Clinical and radiographic evaluation (Fig. 2E).	Clinical: symptoms free. Radiographic: increase of bone density.
October/2020	2nd follow-up	Clinical and radiographic evaluation (Fig. 2F).	Clinical: symptoms free. Radiographic: increase of bone density and zone of hard tissue-like spicules aspect.

Appts.=Appointments; UFRGS, Federal University of Rio Grande do Sul.

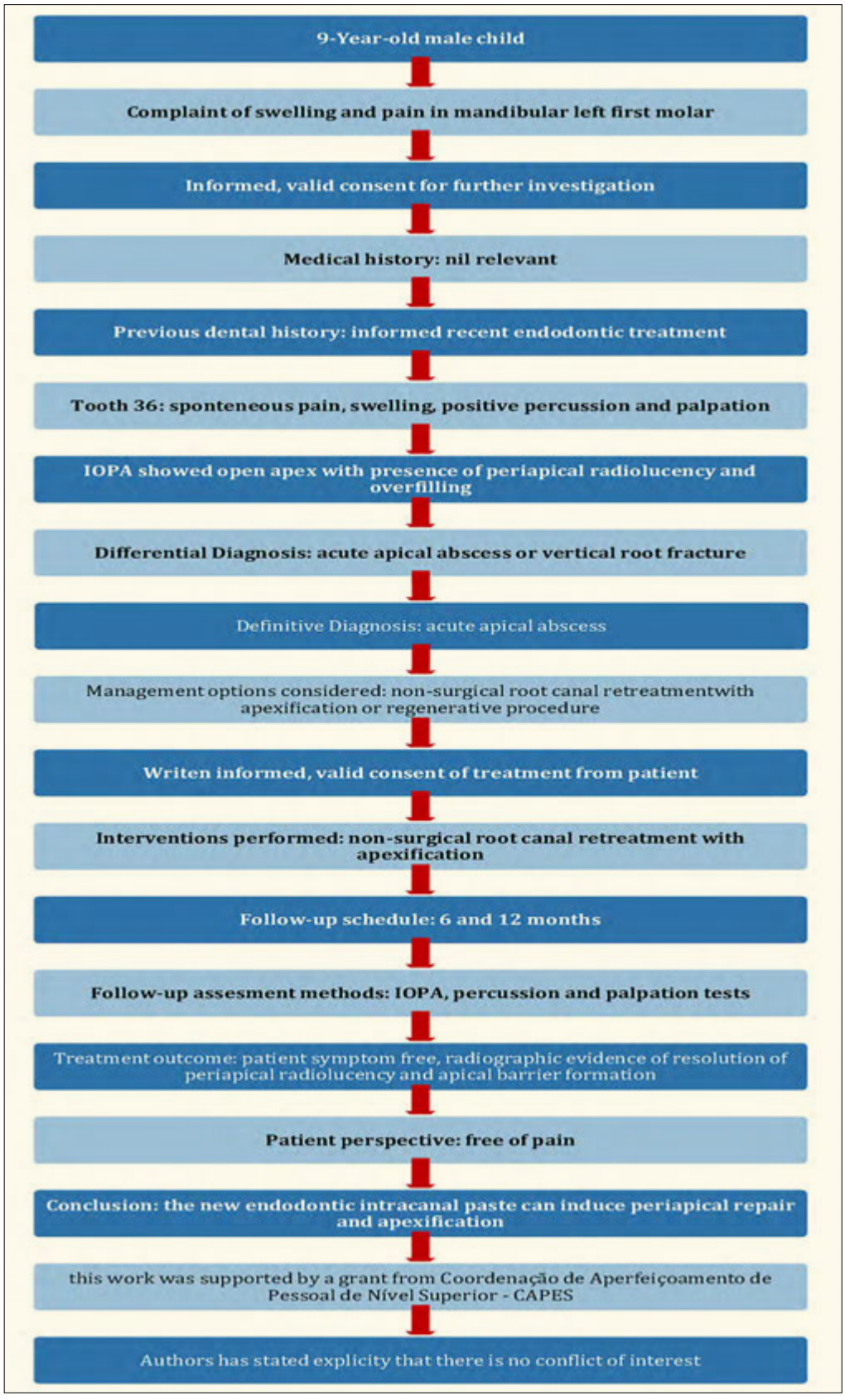

Figure 1
PRICE 2020 flowchart (Nagendrababu et al. 2019, Nagendrababu et al. 2020) showing the steps involved in the case report. IOPA, intraoral periapical radiograph.

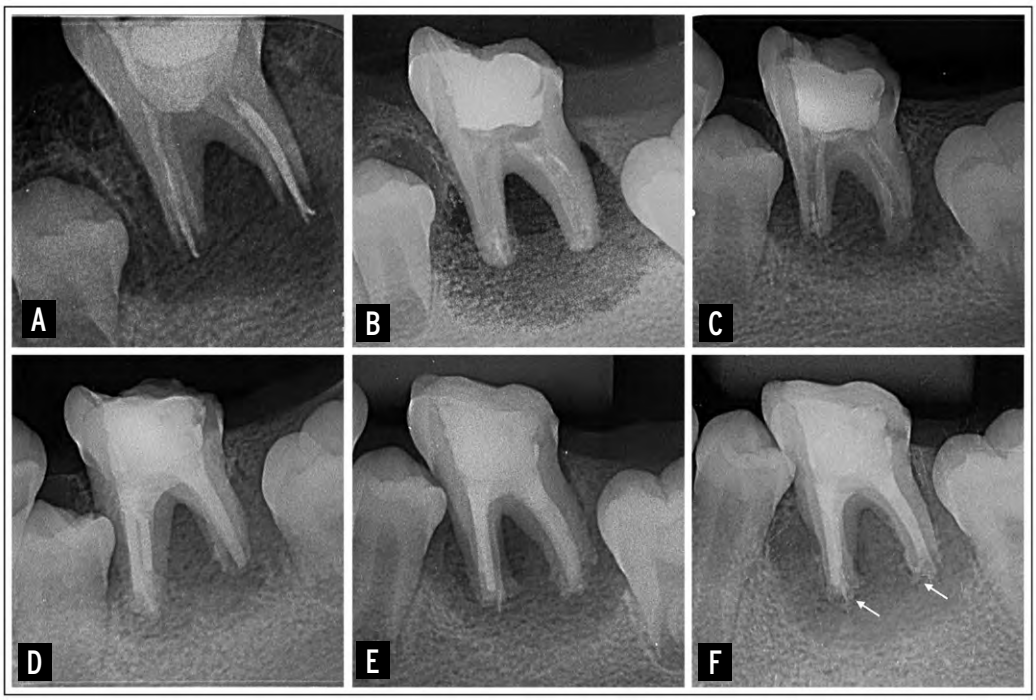

Figure 2
Intra oral periapical radiographs of the case report.
A) Pre-treatment, diagnosis image; **B)** Intra-treatment, endodontic paste insertion evaluation; **C)** Intra-treatment, demonstrating the resorption of endodontic paste at second appointment; **D)** Intra-treatment, final radiograph after the root canal filling; **E)** first follow-up; **F)** secondo follow-up. Hard tissue-like spicules aspect *(Arrows)*.

been proposed (9). Recently, an endodontic paste with α-tricalcium phosphate (α-TCP), calcium tungstate, amoxicillin microspheres (AMX-MS), and indomethacin nanocapsules (IndOH-NC) was formulated to propose a new method of delivering active agents to regions with difficult access due to anatomical complexities present in teeth that need endodontic treatment (10). Also, this in vitro study showed reliable physicochemical properties with no cytotoxicity when tested in fibroblastic (3T3-L1) cell line, and antimicrobial activity against planktonic bacteria and *Enterococcus faecalis* (10). Further, the experimental paste induced a faster wound healing of fibroblasts than a commercially available calcium hydroxide paste (10).
Although several studies showed promising results for drug carriers and bioactive materials for endodontic use, materials with combined antimicrobial, anti-inflammatory, and bioactive properties are not commercially available. After reliable laboratory results of new materials, case reports are the next step at bench-to-chair translation to clinical use. This case report presented the use of a new endodontic paste to retreat an open apex tooth diagnosed with acute periradicular abscess.

Case report

This clinical case is reported according to Preferred Reporting Items for Case reports in Endodontics (PRICE) 2020 guidelines (11, 12). The case management timeline is summarized in table 1 and figure 1. A 9-year-old male child was referred to the School of Dentistry of the Federal University of Rio Grande do Sul in April 2019 for assessing inclusion in a randomized clinical trial (RCT) (CAAE nº 09824919.0.00005347).
The patient reported moderate spontaneous pain aggravated by mastication and swelling in the region of the left lower permanent first molar (tooth #36). There was no significant medical history. Dental history revealed previous endodontic treatment with adequate composite resin restoration in #36 performed six months before the first appointment. Extraoral examination revealed edema without floating-point on the mandibular left side with tenderness to palpation and vertical/horizontal percussion in the #36. An intraoral periapical radiograph (VistaScan Mini Easy, Dürr Dental, Germany) revealed unsatisfactory previous endodontic treatment with voids and overfilling, incom-

plete rhizogenesis, and extensive radiolucent area (Figure 2a). According to clinical and radiographic signs and symptoms, tooth #36 was diagnosed with acute periradicular abscess. After, the agreement by the child guardian and the informed consent was obtained to perform an endodontic retreatment procedure using the new endodontic paste with drug delivery systems as intracanal medication on tooth #36.

In the same appointment, under papillary anesthesia with 2% lidocaine containing 1:100,000 epinephrine (Alphacaine, DFL, Rio de Janeiro, RJ, Brazil), cavity access was performed under rubber dam isolation using a round diamond bur (No.1015; KG Sorensen, São Paulo, SP, Brazil) underwater cooling until gutta-percha was visualized. Irrigation with 2.5% NaOCl (Asfer, São Caetano do Sul, SP, Brazil) was performed, and a #4 Gates Glidden Drill (Dentsply Maillefer, Ballaigues, Switzerland) was introduced into the cervical third of the root canals (distal (D), mesiobuccal (MV) and mesio-lingual (ML)).

The gutta-percha and endodontic sealer of previous treatment were removed with a Clearsonic R1 ultrasonic insert (Helse Ultrasonic, Ribeirão Preto, SP, Brazil) and 2.5% NaOCl irrigation. After that, the #60 file (Dentsply Maillefer, Ballaigues, Switzerland) was introduced into the root canals at the provisional working length (14mm) based on the diagnosis radiograph (Figure 2a), and gentle brush movements were performed on the walls. At the end of this procedure, a supplementary cleaning protocol was realized with 2.5% NaOCl solution and EasyClean instrument (Easy Dental Equipment, Belo Horizonte, Minas Gerais, Brazil) in three 20s cycles under 800rpm rotation and 200g.cm^2 of torque, with the renewal of the solution between each cycle. Afterward, the same procedure was performed with 17% EDTA (Fórmula & Ação, São Paulo, SP, Brazil). The root canals were then aspirated with an aspiration tip (Endo Tips, Angelus, Londrina, Paraná, Brazil) and dried with #80 absorbent paper tips (Dentsply, Petrópolis, RJ, Brazil).

The endodontic paste was prepared with 1 g of amoxicillin microspheres, 0.2 g of α-TCP, 0.4 g of CaWO4 (Sigma-Aldrich Chemical, Inc., St. Louis, MO, USA), and 0.4 mL of IndOH-NC suspension (10). The paste was inserted into a medium flow precision tip (Maquira, Maringá, Paraná, Brazil) adapted to a precision applicator (Maquira, Maringá, Paraná, Brazil). The set was placed in the cervical third of each root canal, and the paste was inserted. A base of temporary restorative material (Villevie, Joinville, Santa Catarina, Brazil) was performed, and for the restoration procedure, the etchant (Dentsply Sirona, Pirassununga, SP, Brazil) was applied at enamel for 15s, rinse for 15s, air-dry to remove excess water. Then, the adhesive Scotchbond Universal Adhesive (3M ESPE, St Paul, USA) brushed for 20s in enamel and dentin with vigorous agitation, gently air thin for 5s and light-cure for 10s (Radii cal, SDI, Victoria, Australia). Resin composite (Filtek Z25, 3M ESPE, St Paul, MN, USA) was placed in increments to restore the cavity. Each increment was photo-activated for 20st (Figure 2B).

The patient was scheduled for a new appointment after 30 days and did not return in the combined period. Numerous attempts to contact his guardians were made, and only in September 2019, the patient returned for the second appointment. Clinically, the patient was asymptomatic, and radiographically it was observed radiolucent area regression compatible with the repair process and mineralized barrier formation in the apical portion (Figure 2C). Under rubber dam isolation, a new access activity was performed, and the paste was removed with 2.5% NaOCl solution while stirring with the EasyClean instrument in 3 cycles of 20s and 17% EDTA under the same agitation protocol. Final saline irrigation was performed, and the root canals were aspirated and dried with #80 absorbent paper tips (Dentsply Maillefer, Ballaigues, Switzerland).

Apical barrier formation was verified clinically by a #80 absorbent paper tip. With this paper point, inside the root canal, touching the barrier, the working length was determined (Distal=16 mm, Mesio-bucal=16 mm, Mesio-lingual=16 mm).

The filling was performed with MTAFill-apex sealer (Angelus, Londrina, PR, Brazil) and gutta-percha (Dentsply, Petrópolis, RJ, Brazil) by the lateral condensation technique. Root canal orifices were sealed with Glass Ionomer Cement (Riva self-cure/SDI, Bayswater, Victoria, Australia) and coronary sealing was performed with Z250XT composite resin under the same previous protocol described (Figure 2D).
In April 2020 (after 12 months of the first appointment), the patient returned for the first follow-up. He reported no pain or swelling. Radiographically, it was observed progressive regression of lesion size with increased density of regenerated trabecular bone tissue (Figure 2E). No adverse events were reported.
The patient was recalled in October 2020 for the second follow-up visit. He remained asymptomatic without intraoral and extraoral signs of abnormality. The patient reported that he was free of pain since the end of the first appointment. Although a complete bone repair has not yet occurred, radiographically was observed a continued increase in density of the regenerated trabecular bone surrounding tooth #36. At the external surface of the apical third was observed a radiopaque zone of hard tissue-like spicules aspect (Figure 2F).
All procedures were conducted under magnification with a surgical microscope (DFVasconcelos, Valença, RJ, Brazil). Radiograph images were viewed and interpreted by two independent endodontists. The images were assessed on a 21″ LED screen where image brightness and contrast could be changed using the software VistaScan (Dürr Dental, Germany).

Discussion

This is the first clinical report assessing the use of a new endodontic paste with controlled drug delivery systems as intracanal medication describing the formation of an apical barrier of mineralized tissue after endodontic retreatment of an open apex tooth diagnosed with acute periapical abscess. This encouraging result could be related to the polymeric nanocapsules conteined in the experimental paste that are able to carry indomethacin into the inflammation sites. Moreover, the implantation of antibiotic loaded polymeric systems directly to the site of infection and consequently, lowering the amount of amoxicillin needed to achieve the desired antibacterial effect probably contributed to the infection control, favoring the apical repair.
The constant movement of the adjacent structures to the #36 tooth, which occurs due to the permanent teeth eruption process, could have impaired the #36 tooth stability, which may justify the incomplete periapical bone repair observed until the present moment. Nevertheless, the periapical lesion regression in the present case could be explained by the chemical-mechanical action of irrigant solutions, endodontic instruments, and the antimicrobial and anti-inflammatory effects of intracanal endodontic paste. Calcium hydroxide paste, routinely used in the referred clinical situation, demonstrated low effectiveness in postoperative pain control (4). Furthermore, it has been shown that dentin's buffering action can counteract the antimicrobial activity of calcium hydroxide (13). Acute endodontic infections present multispecies microbial communities, being strict anaerobes (Porphyromonas, Prevotella, and Parvimonas), the most frequent species isolated/detected inside the root canal (14). Moreover, *E.faecallis* bacteria, one of the most prevalent species in cases of refractory infections to endodontic treatment (15, 16), has shown resistance to medium alkalinization caused by calcium hydroxide (13, 17). The experimental endodontic paste has demonstrated efficacy against *E.faecallis* and planktonic bacteria (10), probably attributed to amoxicillin delivery at the infection site (18).
Further, no pain was reported after the first intervention. Indomethacin is a nonsteroidal anti-inflammatory agent inhibiting prostaglandin synthesis by reversibly blocking cycloxygenases 1 and 2 (COX-1 and COX-2) action (19). The systemic use of oral indomethacin shows adverse intestinal and gastric effects due

to the non-selective action of COX-1 and COX-2 enzymes (20). Controlled drug release could overcome the issues related to systemic antimicrobial and anti-inflammatory administration (21).
In the present case, the new endodontic paste was able to induce mineralized tissue barrier formation, observed clinically and radiographically at the follow-up periods. Bezgin *et al.* (2012) each with at least one necrotic permanent central incisor requiring apexification treatment, were selected for this study. Twenty-two selected teeth were divided into two test groups (10 CHP and 12 CHPP (22) observed an average of 11 months for mineralized tissue barrier formation in teeth diagnosed with acute periradicular abscess treated with calcium hydroxide-based medication. In this case report, at the second appointment (5 months after filling the root canal with the paste), a mineralized barrier formation at the apex was observed. The formed apical barrier could be explained by the antimicrobial and anti-inflammatory action associated with a bioactive calcium phosphate filler (10). Further, alfa-TCP influences fibroblast cell migration, differentiation, and proliferation of mineralized tissue producing cells, favoring the healing process and repair of periradicular tissues (9, 23).
These parameters may suggest an apexification process induced by the new intracanal endodontic paste. An apical barrier is required to avoid bacteria and its toxins from the root canal into the periradicular tissue and act as a base preventing root canal filling extrusion (24). Besides the mineralized barrier induction, at the last follow-up appointment, was observed a radiopaque zone in spicules aspect at the external apical third surface (figure 2F) which differs radiographically from the image observed when MTA or calcium hydroxide paste are used for the apexification process (2, 25). However, to be sure regarding the type of tissue formed, a histological evaluation should be performed.
A possible limitation of this case report was the lack of standardization of the diagnosis radiography as the patient had pain while chewing, precluding the use of a positioner device. However, without pain, the subsequent radiographs were standardized enabling follow-up. Besides the absence of standardization of the first image, a mineralized barrier and the lesion regression could be observed.
Several new materials are developed in recent years to increase the clinical outcomes of endodontic treatments. However, the translation of bench results to the chair-side does not follow the same speed. The literature shows that a breakthrough discovery could take about 17 years to be incorporated into the clinical routine (26, 27). To overcome this issue, new materials screen in vitro and translation to clinical condition is of paramount importance. In this way, the knowledge translation of the state-of-the-art research to the standard of care could enhance clinical outcomes. Although case reports are the first line of evidence in oral health and randomized clinical studies are necessary, the use of a new endodontic paste with reliable in vitro results was translated to clinical application with promising outcomes, shedding light on immature permanent teeth treatment.

Conclusions

The case outcome showed that the paste might be an efficient alternative to conventional apexification materials.

Clinical Relevance

The use of a new endodontic paste with controlled drug delivery system could be used for apexification in immature teeth.

Conflict of Interest

The authors declares that there is no conflict of interest.

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CASE REPORT

Clinical management of a dens in dente type 3, with five canals and acute apical periodontitis in a maxillary lateral incisor

ABSTRACT

Aim: *This report describes the clinical management of a dens in dente type 3 in a maxillary lateral incisor with five canals and acute apical periodontitis in a ten years old child.*

Summary: *An upper lateral incisor presenting dens in dente type III necrotic pulp and acute apical periodontitis was treated. After antibiotic therapy, root canal treatment was initiated and five root canals were located, four converging to an apical pulp chamber. All canals were enlarged using hand files, irrigated with sodium hypochlorite ultrasonically activated. Calcium hydroxide was placed into the canals. The patient missed his next appointment. Eight months after, the canals were re-instrumented, and calcium hydroxide was placed again. Three weeks later the five canals were filled with gutta-percha and an epoxy resin sealer, using a warm technique. Four of the canals were interconnected. Dens in dente was restored with a metal cast post with three retainers and a full porcelain crown. After three years, the periapical lesion showed healing.*

Key learning points:

- *Despite its very complex anatomy type III dens in dente can be successfully treated with conventional root canal treatment.*
- *To achieve success in each particular case when root canal therapy is needed, the clinician should be aware of the diverse clinical techniques available. The use of magnification with clinical microscope, ultrasonic activated irrigation, use of intracanal medication, and warm filling technique are encouraged.*
- *A restoration with a specific cast post, with three retainers, was used due to its particular root anatomy.*

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Introduction

Dens in dente is a development anomaly resulting in abnormal morphodifferentiation of tooth structure (1). This anomaly has also been described as dens invaginatus, dilated gestant odontome and invaginated odontome. Dens in dente shows a broad spectrum of crown and root morphological variations. Can present a bigger cingulum that sometimes appears as another cusp or a small and deep pit in the cingulum. Crown variations of the affected tooth can go from microdontia to macrodontia, having peg or barrel shaped (2, 3).

Radiographically, the dens in dente is observed as a radiopaque mass with a density similar to that of enamel or dentine. It invaginates from the cingulum towards the inside of the root canal, leaving a communication from the oral cavity to the pulp space. Having a great variety in shape and size, it has the appearance of a loop, a pear or a tooth inside another tooth (1, 3). Several causes are considered as etiology: increased growth pressure on the affected bud tooth, fast proliferation or focal growth retardation of specific areas of internal enamel epithelium[4]. This defect on dental bud leaves to a folding of the foramen coecum before calcification occurs (3, 4). Histologically, a dens in dente is a structure composed of enamel, dentine and connective tissue. The interior enamel is hypomineralized, but the dentine can be uniformly mineralized or irregularly structured, that may contain strains of connective tissue or thin communications to the dental pulp (3, 5).

Oehlers (6) developed a classification for these anomalies based on the extension of the dental structure involved as follows: type one, an enamel invagination in the crown only; type two, an enamel-lined invagination that invades the root but remains confined within it as a blind sac, and may communicate with the dental pulp; and type three, an invagination that extends from the crown to the apex and can communicate laterally or apically as a second foramen.

The reported incidence of dens in dente is from 0.3% to 10%, and the most affected tooth is the maxillary lateral incisor (3, 7, 8).

Many treatment modalities for dens in dente are suggested, such as preventive and conservative treatment (9, 10, 11), non-surgical root canal treatment (5, 11-14), a non-surgical-surgical combination (2, 15-17), or tooth extraction7. Besides instrumentation of the root canals, some cases are treated with calcium hydroxide as intracanal medication to induce closure and promote periapical repair (5, 7, 12, 18).

The objective of this case report is to present the non-surgical endodontic root canal treatment and restoration of a maxillary lateral incisor dens in dente type 3, five root canals, and periapical lesion.

Report

A 10-year-old male patient from western México, presented with swelling and pain in the right infraorbital area (Figure 1A). He had no systemic disease or medical history relevant to the case. He reported direct trauma to the area with a soccer ball six months before the appointment. Right central and lateral permanent incisors and temporal canine were very sensitive to chewing by four days, which was decreasing until disappearing at the second week after the trauma. Clinically, the right maxillary lateral incisor had a barrel shape (Figures 1B and 1C). Thermal and electric tests were negative while neighbor teeth were positive. Radiographically, a dens in dente type 3 with a radiolucent periapical lesion was observed (Figure 2A). Necrotic pulp with an apical acute periodontitis diagnosis was made. As a first therapeutic option, conventional endodontic treatment was suggested. Periapical surgery was considered if no healing was observed with conventional treatment. After explaining to the patient´s mother the clinical conditions, she gave the required informed consent for the procedure. It was prescribed 400,000 units of oral Penicillin every 8 h for eight days and 200 mg of oral Ibuprofen every eighth for three to five days.

Figure 1
A) Clinical image of the patient, with inflammation in the suborbital region. **B, C)** The inflammation extends in the vestibule. Incisal and vestibular view of the lateral incisive, with its "barrel shape".

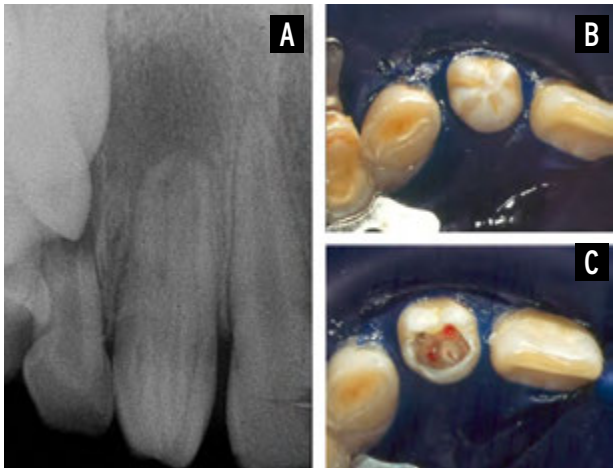

Figure 2
A) Preoperative radiograph showing a triple dens in dente and apical periodontitis. Note the apical pulp chamber. **B)** Barrel shaped crown with five tubercules. **C)** After endodontic access, two root canals presented bleeding.

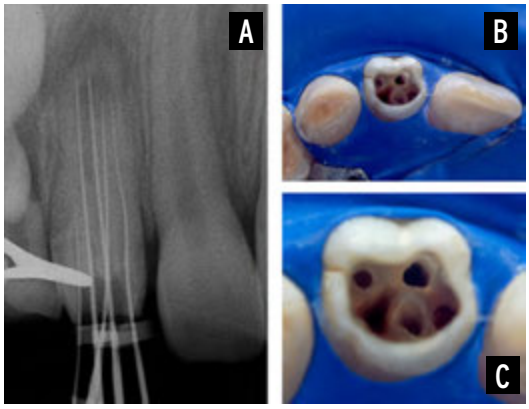

Figure 3
A) Radiographic image shows five root canals. **B, C)** Clinical images of the pulp chamber and the five canals, after root canal shaping.

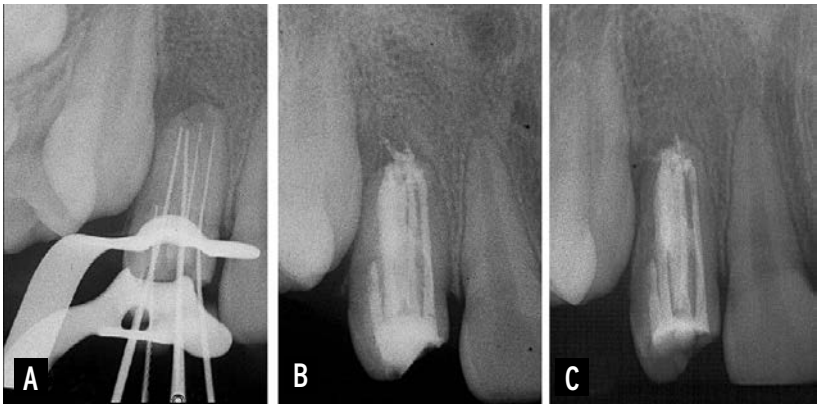

Figure 4
A) Eight months after the initial appointment. The apical radiolucent area had decreased in size. **B)** Postoperative radiograph with the obturated canal system and slight extrusion of material. **C)** One year after the beginning of treatment, a follow-up radiograph shows periapical healing of the previous lesion, and a part of the extended material has been resorbed.

Eight days after the initial appointment the patient returned with no swelling or symptoms. Local infiltration of Lidocaine 2% epi 1x100,000 was applied. Rubber dam isolation was obtained by placing the clamp on the first deciduous molar; cyanoacrylate was applied around the tooth to get a better seal of the dam to the tooth (Figure 2B). At this point, all of the clinical procedures were performed with the aid of a clinical microscope (OPMI Pico, Zeiss, Oberkochen, Germany); the access cavity was done with a #1 round high-speed carbide bur. With 0.10 stainless-steel K-files (Maillefer/Dentsply, Ballaigues, Switzerland), five root canals were located and negotiated, which were named mesiobuccal MB, distobuccal DB, distopalatine DP, centropalatine CP, and mesiopalatine MP. The DV, CP, and MP canals were necrotic, the other two were vital (Figure 2C). The working length was established with the radiographic method. The length of the DB canal was 13 mm and separated

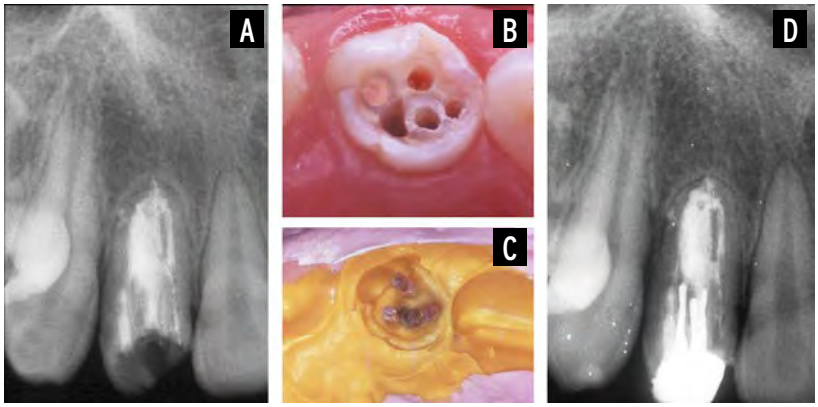

Figure 5
A) Radiography and **B)** clinical images showing the desobturation of four canals and silicon impression **(C)**. The metal post cast with three retentions cemented **(D)**.

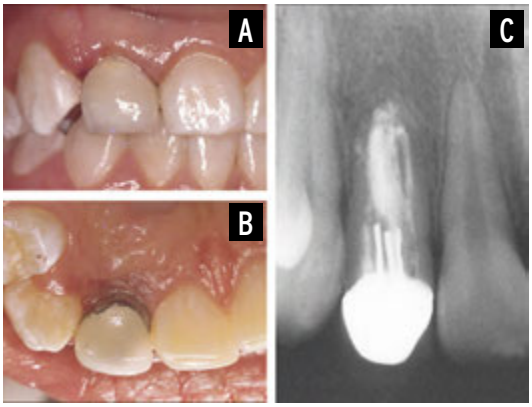

Figure 6
A, B) Clinical images of porcelain crown cemented. Follow up radiography, three years after the beginning of treatment **(C)**. The previous apical periodontitis is healed.

from the other canals. The rest measured 19 mm and converged to what seemed to be an apical pulp chamber (Figure 3A).
All the canals were hand instrumented to a #35 Flexofile (Maillefer/Dentsply), irrigated with 1% sodium hypochlorite (NaOCl) along with three, 20 seconds cycles of ultrasonic activated irrigation (UAI), with an Irrisafe tip #20 (Satelec-Acteon, Merignac, France) in a piezoelectric unit (Varios 370 NSK, Tochigi, Japan). Canals were dried with sterile medium paper points (Kerr, Glendora, USA) and filled with REDTA (Roth Int. Chicago, USA) for 5 minutes, flushed again with NaOCl and dried again with sterile medium paper points (Kerr) (Figures 3B and 3C). Pure calcium hydroxide (Sultan, York, USA) mixed with saline to a thick consistency was placed with a #30 Lentulo spiral (Maillefer/Dentsply) inside the canals, and the access cavity was carefully cleaned and sealed with glass ionomer cement (Fuji II LC, GC Corp, Tokyo, Japan). Ibuprofen (200 mg every 8 hours) was indicated if necessary.
The patient missed his second appointment and did not reschedule. Eight months later returned and presented an enamel fracture in the mesial-incisal angle. During the elapsed time the patient had no signs or symptoms. The working length was verified (Figure 4A) root canals were cleaned again with a #35 hand file, irrigated with 1% NaOCl and UAI. Calcium hydroxide mixed with saline was used as intracanal dressing. Three weeks later the patient remained asymptomatic, and calcium hydroxide was removed from the root canals with UAI for two minutes and EDTA final irrigation. Canals were obturated with thermo plasticized gutta-percha and AH Plus (Dentsply DeTrey, Konstanz, Germany) by continuous wave technique, with an Elements Obturation unit (SybronEndo, Glendora, USA). Four root canals showed intercommunication along the root and in the apical pulp chamber; the distobuccal canal looked separated (Figure 4B). The crown was sealed temporarily with glass ionomer and scheduled in one week for restoration. Cold and electric tests from neighbor teeth were standard.
Unfortunately, the patient missed his appointment for restoration. He returned only after seven months later, with a fracture of almost all of vestibular enamel. Radiographically, the periapical lesion showed healing (Figure 4C). Given the particular root canal anatomy, a cast post with four "fingers" as retainers was indicated. Gutta-percha was removed from four root canals (MB, DP, CP, MP, Figure 5A) with heated endodontic plugger #50 (Maillefer/Dentsply). Internal debris was retired from post spaces with saline irrigation and a K-file #45 and dried with

coarse absorbent paper points (Figure 5B). Then, light-body vinyl polysiloxane impression material (Regular set, Imprint 4 VPS; 3M-Espe, Saint Paul, MN, USA) was carried into post canal spaces with a #30 Lentulo spiral (Maillefer/Dentsply). A partial fine plastic toothpick was inserted in each root canal, to prevent rupture or dislocation of impression material. With heavy body material in a tray, the impression was completed (Figure 5C). Metal post cast with four "fingers" was elaborated with nickel-chrome alloy (Smartbond II non Beryllium, Dental Depot, Ft. Lauderdale, USA). When the metal post cast was tested on the patient, one of the "post fingers" was fractured. Due to the patient's lack of adherence, the decision to cement the post was taken (Figure 5D) with glass ionomer cement (Fuji I LC, GC Corp). In the same appointment, the core was prepared for a full crown, and a vinyl polysiloxane impression (Imprint 4 VPS; 3M-Espe) was made. An alginate impression (Max Print, MDC, Zapopan, México) of the mandibular teeth and a bite register (Imprint 4 Bite, M-Espe), as well as dental color and shades, were taken. A porcelain-crown was elaborated and cemented one week later (Figures 6A and 6B). The mother was informed that the porcelain crown should be evaluated and changed when the patient is an adult.

After three years from the beginning of treatment the patient was symptom-free. A radiograph showed periapical healing (Figure 6C) and the tooth was in normal function.

Discussion

The lateral incisor dens in dente presented unusual morphology, as a barrel-crown shape with deep grooves and pits. The invaginated grooves render more susceptible to accumulate biofilm, impossible to clean with brushing, leading to caries (7). Those morphological defects can lead to direct microorganism invasion, producing pulpitis, necrosis and periapical inflammation (1, 3, 6). On the other hand, direct trauma causes a concussion on pulp and periodontal tissues (19). Intensity, direction, type of trauma, apical development, the age of the patient and time, are factors that influence the response of the oral tissues to trauma. After the concussion, the dental pulp may not respond to cold or electrical tests due by injury, inflammation or pressure on the nerve fibers in the periapical region (20). This affectation in many cases is reversible since, after 2 to 6 months, many traumatized teeth without immediate pulpal response recover normal sensitivity (19, 20).

Given the proximity of the permanent central incisor and the temporal canine adjacent to the lateral incisor, it is very likely that they received part of the soccer ball trauma. However, both central incisor and canine showed a standard response to vitality tests. We assume that direct trauma six months prior leaded to the affectation of pulpal irrigation of lateral incisor, and with its critical anatomical conditions of possible micro-communication from the dental biofilm trough pits and grooves, invasion of microorganisms to the pulp produced necrosis and subsequent periapical abscess.

Freshly erupted teeth in which are observed deep palatal grooves or foramina coeca, and the presence of dens in dente are suspected, must be diagnosed as soon as possible (2, 3), and treated conservatively with fissure sealing or composite restoration before microbial invasion occurs (3, 7). A strict periodic clinical control is mandatory, in order to detect any pathological change (7, 8). If bacterial contamination to the pulp is prevented, and no signs of pulpal pathosis presented, no further treatment is indicated (3, 18).

The case presented had three necrotic and two vital canals, but we decided to treat them all as necrotic since four were joined in an apical chamber. Treatment of dens in dente is complicated because of its atypical shape and complex root canal system (1-3). Frequently, treating such cases requires a combination of various endodontic techniques. In complex root canal systems, with isthmus and communication among canals, hand or rotary instrumentation leave untouched areas, where necrotic tissues and bacteria can

remain (21). UAI with NaOCl has shown good results to improve canal and isthmus cleanliness (22), as well as remove calcium hydroxide used as intracanal medication (23).
Holland et al (24) used calcium hydroxide in the treatment of pulpless teeth and associated apical pathology, in order to stimulate healing of the periapical tissues and the formation of an apical barrier. $Ca(OH)_2$ mixed with saline solution as an intracanal medication allows the dissociation of OH^- ions and Ca^{++} ions. The OH^- ions are responsible for the pH rise, which creates its bactericidal effect (25-27). Calcium hydroxide antibacterial activity is due in part to its OH^- ions action on the bacterial cell membrane (26), damaging this important cellular structure that is essential for bacterial metabolic processes. Also, calcium hydroxide inactivates lipopolysaccharides of Gram-negative bacteria (25).
Although prolonged use of calcium hydroxide as intracanal medication has been pointed out as a factor that can decrease resistance to root fracture, a recent study (28) has shown that the intracanal dressing for nine months of calcium hydroxide does not produce these effect, compared to the control teeth. The factor that leads to the observed increase in radicular fractures in immature teeth is the decreased resistance due to its thin dentinal walls in immature teeth (28). In this particular case, a metal cast post with thin retentions was decided, in order to conserve as much as possible dentine structure from the root, to keep the root resistance in the long term.
Several recently used techniques and materials should be evaluated in the diagnosis (CBCT) and management of these complex cases, since they can provide more conservative therapies. In cases of pulpal necrosis and immature apex, it is possible to perform endodontic regeneration procedures by using hydrogel scaffolds derived from decellularized and demineralized bovine bone (29), or scaffolds from blood clot with the aim of inducing the formation of mineralized tissue within the root, leading to strengthening of the root walls. The filling of these very complex anatomies, which can present multiple inter-canal septa, can be carried out with calcium silicate cements in its entirety, without gutta-percha (30).
On the other hand, crown and root malformation in some dens in dente can lead to periodontal lesions, which can be managed with regenerative techniques and materials (29, 30), which allow more conservative treatment approaches for patients. The clinician should consider the possibility of periapical surgery in some cases (2, 3).
The combined use of disinfection strategies (hand filing and passive ultrasonic irrigation with NaOCl), the use of calcium hydroxide and thermoplasticized filling technique and a modified cast post, allowed the successful treatment of this case that presented particular anatomy. In such cases like the one presented here, the clinician should use biological and technical means to treat the patient conservatively and maintain the tooth successfully.

Conclusions

Dens in dente type 3 offers a unique challenge to clinicians, due to its complex and unpredictable anatomy presented in every case. From diagnosis and through each of the stages of endodontic therapy and restoration, the canal system of dens in dente presents difficulties in localizing, cleaning, shaping, disinfecting, filling and restoring this complex canal system. In this case, through conventional endodontic therapy with the aid of magnification, optimization of irrigation with ultrasonics, long term of calcium hydroxide intracanal medication and a warm filling technique, it was possible to solve a complex anatomical case.

Clinical Relevance

In the treatment of Dens in dente type 3, the clinician must be aware of the different techniques available, as magnification with the clinical microscope, ultrasonic activated irrigation and intracanal medication as well as thermo plasticized filling techniques, in order to achieve success in the treatment of this anatomical anomaly.

Restoration of these abnormal crowns and roots represents a challenge for the clinician, in order to obtain functionality and aesthetics.

Conflict of Interest

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

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CASE REPORT

Endodontic management on a C-shaped mandibular molar fused with a supernumerary tooth: a report of a rare case

ABSTRACT

Aim: *Fusions involving mandibular molars and supernumerary teeth are rarely reported. The complex internal anatomy makes the endodontic treatment of these teeth a challenge for the clinician. This report describes the endodontic management of a rare case of a C-shaped mandibular molar fused with a supernumerary tooth.*

Summary: *A 29-year-old male was referred for endodontic treatment of the right mandibular second molar. The initial clinical examination indicated atypical anatomy of this tooth, with the presence of a "supernumerary cusp". Cone-beam computed tomography (CBCT) images showed that the cusp was a supernumerary tooth, with its canal separated in the cervical third, but fused in the apical third to the second molar canals, forming a single C-shaped canal. After clinical and radiographic examination, the diagnosis was irreversible pulpitis. The endodontic treatment was performed with the aid of a dental operating microscope. The root canals were instrumented using the crown-down technique and irrigation using 2.5% sodium hypochlorite (NaOCl). Passive ultrasonic irrigation was performed (2.5% NaOCl and 17% EDTA solutions) followed by obturation using the thermoplasticization technique. No clinical or radiographic changes were noted at the 12- and 24-month follow-up visits.*

Key-learning points:

- *The analysis of CBCT images and the use of magnifying tools are essential for the diagnosis and treatment of teeth with complex root canal anatomy.*
- *For teeth with complex anatomies, in addition to the traditional methods of root canal shaping and filling, it is necessary to associate methods that enhance the cleaning and disinfection of the root canal system.*

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Introduction

The success of endodontic therapy depends on adequate debridement and filling of the root canal system (1). Clinicians need to have adequate knowledge about the morphology of the root canal and its possible variations to achieve satisfactory outcomes in endodontic treatments (1, 2). The presence of unusual and complex variations in root canal morphology may contribute to unsuccessful treatment since it can make it difficult to locate and negotiate the canals, as well as their subsequent management (1).

The C-shaped root canal system is an anatomical anomaly with a cross-sectional shape similar to the letter 'C' (2). Its configuration has a higher prevalence in mandibular second molars and is rarely related to other teeth, such as premolars, mandibular first or third molars, and maxillary molars (2, 3). The prevalence ranges from 2.7 to 55% in different ethnicity, with higher values in oriental populations (3). C-shaped root canal anatomy may vary along the root length, with individual canals that have a kind of fin or net connecting them (4). In addition, the canal walls may be of different thicknesses, in which the lingual wall is generally thinner (4). Due to the peculiarities of its clinical characteristics, this anatomical configuration may present challenges in cleaning, shaping, and filling of the root canal (1, 4).

The etiology of supernumerary teeth is still not entirely clear (5). Hyperactivity of the dental lamina, heredity, and association with syndromes are factors that have been extensively investigated (5). These teeth can differ in number or morphology and occur anywhere in the dental arch, as well as can be fused to permanent teeth, most commonly in the anterior region of the maxilla (5). However, fusions involving supernumerary teeth with mandibular molars are rarely reported in the literature (6). These fusions can be partial or total, depending on the stage of development of the teeth at the time of union (7). Fused teeth usually have independent root canals with combined dentinal walls (8). If these teeth have endodontic involvement, their treatment becomes a challenge for the clinician (6, 7).

According to the American Association of Endodontists, cone beam computed tomography (CBCT) should be considered the imaging modality of choice for endodontic treatment of teeth with potential suspicion of complex morphology (3, 9). In cases of C-shaped root canals or fused teeth, CBCT facilitates and improves the understanding of the root canal morphology, as it provides a three-dimensional image of the same (3, 9). In addition, the use of magnifying tools for endodontic therapy, such as the dental operating microscope, can increase the effectiveness and precision of treatment, especially in teeth that have some particular anatomical complexity (10). Therefore, the present case report describes the endodontic management of a C-shaped root canal in the mandibular second molar fused with a supernumerary tooth, with the guidance of a CBCT image and the use of a dental operating microscope.

Report

A 29-year-old Caucasian man, in generally good health (ASA I), was referred by another clinician for endodontic treatment. The patient was complaining about spontaneous, intense, and localized pain in the lower right second molar, which started two days earlier. In an intraoral examination, the tooth presented an atypical supernumerary cusp fused by a buccal surface (Figure 1A), was free of cavities or restorations, probing depth was within normal limits (less than 3 mm) and no pathologic tooth mobility was observed. It showed a mild response to percussion/palpation and pain was exacerbated when the cold test (Roeko Endo-Frost; Coltene, Langenau, Germany) was performed. It was observed an abrasion lesion in the supernumerary cusp (Figure 1A). Also, the patient came in possession of panoramic radiography (Figure 1B) and a CBCT of the mandible, with section thickness (voxel) of 0.099 mm and 0% distortion in axial and transversal (parasagittal) sections, and 3D, sagittal, coronal, axial and transversal

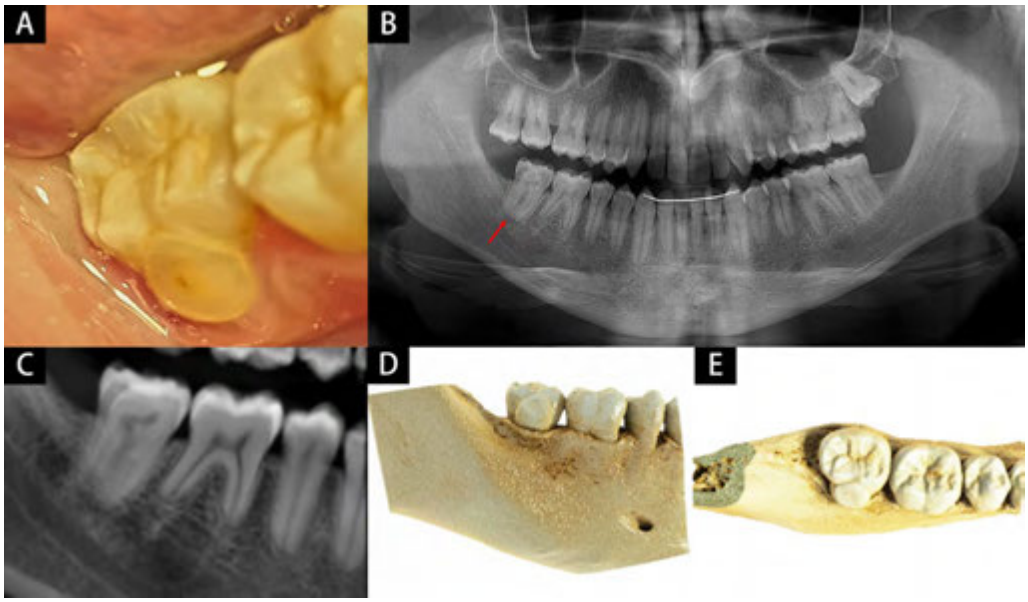


Figure 1
A) Clinical image before endodontic treatment: atypical supernumerary cusp fused with the mandibular second molar by buccal surface. **B)** Panoramic radiograph: red arrow indicating the tooth to be treated. **C)** CBCT periapical reconstruction. **D, E)** CBCT 3D reconstructions: **D)** buccal and **E)** occlusal views.

reconstructions. At tomography and 3D reconstructions evaluation, it was noticed that the 'atypical supernumerary cusp' was a supernumerary tooth characterized by increased height and reduced mesiodistal width. It was also realized that the supernumerary canal was separated in the cervical third (Figure 2AB), but fused in the middle (Figure 2CD), and apical thirds (Figure 2EF) to the second molar canals, forming a single C-shaped canal in the buccal direction. According to a previous study,(11) isthmuses in root cross-sections were classified as type III (incomplete isthmus existing above and/or below a complete isthmus). Considering clinical and radiographic findings, the diagnosis was irreversible pulpitis and endodontic treatment of the tooth was proposed. An informed consent form was obtained from the patient, to perform the endodontic intervention.

After the right lower alveolar and buccal nerve block (2% mepivacaine with 1:100.000 epinephrine [DFL, Taquara, Brazil]), isolation with a rubber dam was performed and secured with liquid dam material (Top Dam; FGM, Joinville, Brazil). Then, all treatment was conducted under operative microscopy (MC-M3101; DF Vasconcellos, Valença, Brazil). Initially, coronary access was performed in the center of the occlusal surface of the second molar with a high-speed diamond bur (#1014; KG Sorensen, Cotia, Brazil), primarily to access the mesial and distal canals. As it was not possible to locate the supernumerary canal, another access was made in the center of the occlusal surface of the supernumerary cusp (Figure 3A). A size 10 K-file (Dentsply Maillefer, Tulsa, USA) was introduced into the root canals, under copious irrigation with 2.5% sodium hypochlorite (NaOCl) solution to ensure patency. Next, the canals were measured with an electronic apex locator (Root ZX II; J Morita, Kyoto, Japan) and the working length (WL) was established in the apical foramen.

Then, the root canals were prepared with the Reciproc Blue R25 instrument (#25/0.08; VDW GmbH, Munich, Germany), according to the manufacturer's instructions. At each removal of the instrument for cleaning, the root canals were irrigated with 2 mL of 2.5% NaOCl with the aid of a NaviTip 30-G tip (Ultradent Products Inc, South Jordan, USA) coupled to a 5-mL syringe. After preparation, passive ultrasonic irrigation (PUI) was performed in all root canal system with the aid of an ultrasonic tip (E1 Irrisonic; Helse Ultrasonic, São Paulo, Brazil), alternating 2.5% NaOCl and 17% ethylenediaminetetraacetic acid (EDTA) solution. At this time, the patient complained of intense pain in the tempo-

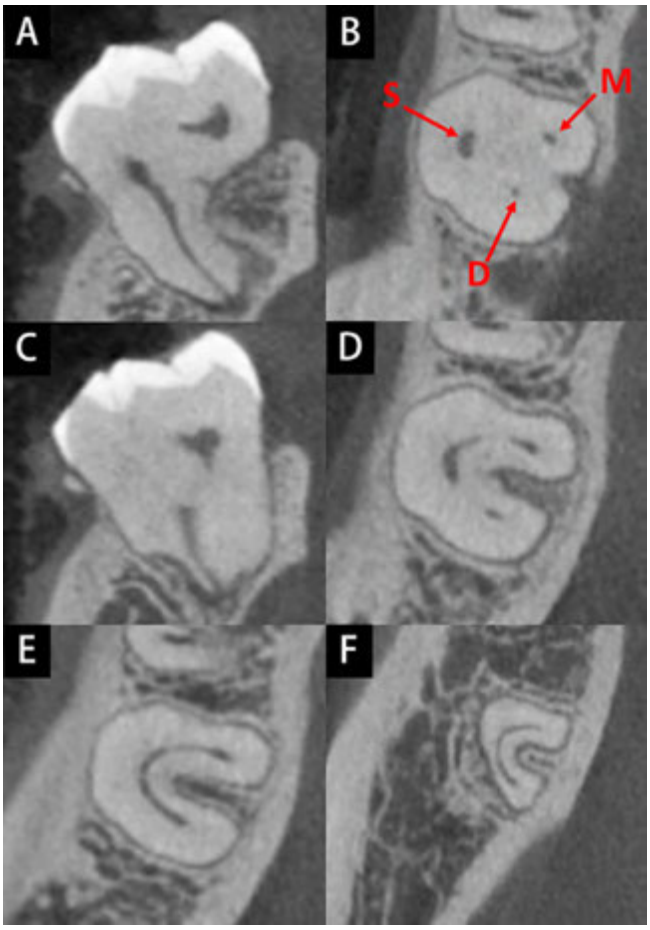
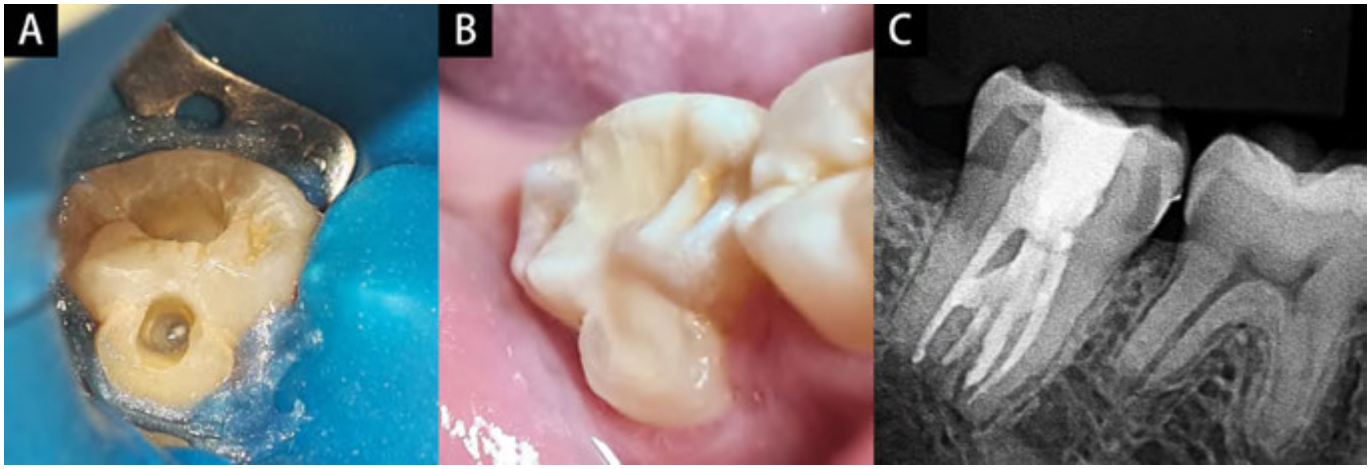


Figure 2
CBCT images. **A)** Transversal section: supernumerary canal separated from the second molar canals in the cervical third. **B)** Axial cervical section: individual mesial (M), distal (D) and supernumerary (S) canals. **C)** Transversal section: supernumerary and second molar canals fused in the middle third. **D)** Axial middle section: supernumerary, mesial and distal canals fused forming a single C-shaped canal. **E, F)** Axial apical sections showing a single C-shaped canal.

romandibular joint and requested that the treatment be stopped. Despite being a diagnosis of irreversible pulpitis, the treatment had to be conducted in two sessions, seeking to respect the patient's request and his joint pain threshold. Therefore, the root canals were dried with sterile absorbent paper points (R25; VDW GmbH, Munich, Germany), and a calcium hydroxide (CH) intracanal dressing (Ultracal XS; Ultradent, South Jordan, USA) was placed (12). After a digital periapical radiograph to confirm the complete filling of the root canals by the CH dressing, the access cavities were sealed with a light-curing, ready-to-use, glass ionomer composite cement (Ionoseal; Voco, Cuxhaven, Germany).

Two weeks later, the patient returned without symptomatology and a second intervention was carried out. After the initial procedures (anesthesia and tooth isolation with a rubber dam), the temporary restorations were removed from the access cavities with a high-speed diamond bur (#1014). To remove de CH paste from the root canals, a copious amount of 2.5% NaOCl solution was activated using an ultrasonic tip (E1 Irrisonic). Next, the canals were dried with absorbent paper points (R25) and obturated with AH Plus sealer (Dentsply Sirona, Tulsa, USA) and gutta-percha cones (R25; VDW GmbH, Munich, Germany). First, the gutta-percha cones were selected and locked 1 mm below the WL. After, the

Figure 3
A) Clinical image during endodontic treatment. Two access cavities were performed: traditional access in the center of the occlusal surface, and in the center of the occlusal surface of the supernumerary cusp to locate the supernumerary canal. **B)** Clinical image after endodontic treatment showing both access cavities restored. **C)** Final periapical radiograph.



selected cones were coated with AH Plus sealer and cemented into root canals. The filling material was thermoplasticized using a McSpadden condenser (#55; Dentsply Maillefer, Tulsa, USA) activated in a clockwise direction, until it reached 5 mm above the WL. Then, the vertical compaction was performed by a manual gutta-percha condenser (#1-4; Odous de Deus, Belo Horizonte, Brazil), and the excess of gutta-percha was removed up to 1mm below the cementoenamel junction. Next, the access cavities were restored with a double seal using glass ionomer cement (Ionoseal) and composite resin (Z250 Filtek; 3M, Saint Paul, USA). After checking the functional occlusion of the tooth, the final periapical radiograph was performed (Figure 3B).

The radiographic and clinical review were performed after 1 month, and the absence of signs and symptoms related to this tooth was verified. The follow-up visits at 12 and 24 months showed no radiographic or clinical changes and the patient was symptom-free.

Discussion

The anatomical variability of root canal morphology is an ongoing challenge for diagnosis and endodontic therapy (6, 7). The presence of a C-shaped canal makes it difficult for the clinician to diagnose, prepare, clean and fill the root canals (1). In the present case, fusion with a supernumerary tooth made the stages of endodontic treatment even more difficult. To date, there are no cases in the literature that report endodontic management of a C-shaped mandibular molar fused with a supernumerary tooth.

The diagnosis in cases of C-shaped canals in molars can be complex, mainly due to its peculiar anatomy (4). This report describes a case of irreversible pulpitis in a healthy second mandibular molar with a C-shaped canal system and fused with a supernumerary tooth. Even in healthy teeth, infection of the pulp tissue can occur if there is a pathway for bacteria to access the pulp cavity (13). This is possible in the presence of traumatic events, which may have caused cracks or fractures, or due to anatomical changes, such as the presence of fusion gaps between the tooth and the supernumerary, as in the present case (13). Thus, microorganisms can invade the non-exposed dental pulp through the dentinal tubules, leading to pulpitis (14, 15). In addition, the patient's age may have been a factor that also influenced the rate of bacterial invasion of dentinal tubules (16). According to Kakoli et al. (16), there is a direct influence of age on bacterial tubular invasion, in which bacterial infection of dentinal tubules occurs to a greater extent and more rapidly in young patients when compared to elderly patients. Therefore, the presence of cracks or union gaps in enamel are areas that require supervision by the clinician, especially in young patients.

Although periapical radiographs are essential for diagnosis and planning in endodontics, two-dimensional images provide more limited information, and CBCT may be helpful in more complex cases (9). The CBCT image is a resource for the clinician, as it allows three-dimensional visualization of the anatomy of the teeth, providing a more detailed view, which can affect the treatment recommendations (9). In the present case, the three-dimensional image was essential, mainly due to the peculiar anatomy of the C-shaped canal fused to a supernumerary tooth. In addition, new strategies implemented recently can contribute the clinician overcome the difficulties that anatomical complexities can present to treatment - such the computer-aided dynamic navigation technology (17, 18). The potential of this technique is to guide the coronary access and location of the orifices of the root canals in teeth with a modified position due to anatomical alterations (17); a recent study (18) showed that the use of dynamic navigation is accurate for this proposal. Thus, the use of CBCT images and a dynamic navigation system can allow better understanding and interpretation of complex anatomical structures, benefiting the management of the case, optimizing the treatment outcome, and providing greater comfort to the patient.

In the present case, the supernumerary canal was separated from the second molar canal system in the cervical third, but merged in the middle and apical thirds, forming a single C-shaped canal in the buccal direction. The understanding and visualization of the complex anatomy of this network of root canals were facilitated with the use of magnifying tools – such as the microscope. The use of the dental operating microscope in endodontic practice has become common since the early 1990s (10, 19). According to Kersten et al. (19), the use of the operating microscope in endodontics increased from 52% in 1999 to 90% in 2007. There are several benefits of its use in endodontic procedures: it facilitates the access and location of the canal orifices, favors the detection of fracture lines, improves the surgical technique, and increases the ability to examine, model, and clean root canals, especially in more complex cases, such as C-shaped root canal anatomy (10).

In a C-shaped root canal preparation, special attention should be paid to the 'isthmus', 'trough', and 'fin', which may contain remnants of pulp tissue and can serve as a bacterial reservoir for future infections (20). Due to these particular anatomical features, cleaning, and shaping these root canals are challenging for the clinician (1). In an *ex vivo* study, the Reciproc Blue file was associated with large percentages of untouched canal walls after preparing C-shaped canals in mandibular molars (1), which makes irrigation an essential step in the endodontic treatment of these teeth, as it allows cleaning beyond of instruments from the untouched areas of the root canal (21). However, dentin tissue debris may also be present on the isthmus and fins during instrumentation (1). Results of previous studies have revealed that the accumulation of dentin debris occurred in all samples of C-shaped canals, regardless of the file system used for the preparation (1, 22). This accumulated debris can compromise the efficiency of irrigation, intracanal dressing, and the sealing provided by the filling (23, 24). Therefore, in this present case report, the PUI was proposed to activate NaOCl and EDTA solutions and also to remove the CH dressing.

The effectiveness of the PUI can be attributed to the production of acoustic microwaves, cavitation, and heat generation (22, 25). PUI has been encouraged to optimize different stages of endodontic treatment (25). Previous studies have reported that the ultrasonic activation of irrigating solutions significantly reduces the debris accumulation within the C-shaped canals, favoring the cleaning of areas inaccessible to the instrumentation and leaving the free space to receive the filling materials, favoring a better seal (22, 25). In addition, PUI has been reported to optimize smear layer removal, especially in the apical third, and the removal of dressings from the root canals (25). Pabel and Hulsmann (25) demonstrated that the highest efficacy in removing the CH dressing from the root canal walls resulted from the use of ultrasonic methods, such as PUI.

Another challenge in the endodontic treatment of C-shaped canals refers to the filling process (26, 27). The absence of three-dimensional filling in the critical areas of the C-shaped canals, as in ribbon-shaped communications, must invariably lead to a greater degree of bacterial microleakage (20, 26). Based on the anatomical complexities of C-shaped canals, the use of thermoplasticized gutta-percha filling techniques has been defended, in which the softened gutta-percha compaction should fill the root canal irregularities (26, 27). In the present case report, we performed the thermoplasticization of gutta-percha cones using a McSpadden condenser, obtaining a satisfactory final result.

Traditionally, root canal obturation is performed using gutta-percha and sealer (28). Currently, there is a trend for endodontic professionals to use resin-based epoxy sealers associated with the warm obturation technique (29). However, the use of thermoplasticized gutta-percha filling techniques should be performed with caution by clinicians, as prolonged use of the compactor can promote apical extrusion of the filling material and exaggerated heating of the sealer (26, 28). Soo et al. (26) demonstrated that the apical

portion of the C-shaped canal proved to be the most difficult part of achieving an adequate filling without material overflow. In addition, the heat generated using thermoplasticization can affect the physicochemical properties of epoxy resin-based sealers (28). A recent study (28) demonstrated that heating AH Plus for 10 or 30 seconds fastened the setting process and decreased its viscosity. However, for this heating time, these changes were considered minor and AH Plus appeared to be a suitable cement for use at high temperatures (28).

Endodontically treated teeth have a higher risk of mechanical failure than sound teeth (30, 31). This can be attributed to the loss of coronal or root structure due to endodontic access or preparation (31). In the present case, direct resin restoration was the treatment performed due to the conservative approach in the coronal access cavities. However, the access cavity preparation by itself tends to compromise the mechanical integrity provided by the sound tooth and allows greater tooth flexion during function, which can result in the fracture of the endodontically treated tooth (31). In the present report, the final restoration was performed consecutively with the endodontic treatment. Despite the double seal using glass ionomer cement, this is usually not recommended due to the long setting time of the AH Plus and can be highlighted as a potential limitation of this case.

Conclusion

Although anatomical variations of root canals are rare, their importance cannot be underestimated, as they can influence the prognosis of individual cases. C-shaped root canal fused with a supernumerary tooth is an anatomically rare condition that demands appropriate management. The use of CBCT imaging and magnifying tools are essential for the diagnosis and understanding of this root anatomy. For these teeth, in addition to the traditional methods of root canal shaping and filling, it is necessary to associate techniques that enhance the cleaning and disinfection, such as ultrasonic activation of the irrigating solution, and better sealing of the root canal system, such as gutta-percha thermoplasticization.

Clinical Relevance

Clinicians need to know and manage anatomical anomalies, such as C-shaped root canals. In the treatment of a fused tooth with C-shaped canals, preoperative analysis of CBCT scans associated with magnifying tools, and appropriate endodontic techniques can lead to favorable outcomes.

Conflict of Interest

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

Acknowledgments

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REVIEW ARTICLE

Dentinal tubule penetration of bioceramic-based versus epoxy resin-based root canal sealers: a systematic review and meta-analysis

ABSTRACT

An ideal endodontic treatment involves filling the root canal system with a sealer that penetrates the dentinal tubules and remains intact. Hence, this systematic review aimed to appraise and analyse the dentinal tubule penetration of bioceramic-based and epoxy resin-based root canal sealers.
Articles published between January 1990 and March 2022 were searched in seven online databases (Google Scholar, PubMed, Web of Science – Core collection, Scopus, Cochrane Library, EBSCO, and Open Grey). Only in-vitro *studies evaluating dentinal tubule penetration of bioceramic-based and epoxy resin-based sealers were selected. The OHAT risk of bias (RoB) tool was employed to analyse the RoB of each article. A two-arm meta-analysis based on the DerSimonian-Laird random-effects model was used to assess the standardised weighted mean differences in dentinal tubule penetration for both sealer types.*
Although bioceramic-based root canal sealers exhibit inferior dentinal tubule penetration than epoxy resin-based sealers, future well-designed studies with standardised evaluation tools and a more control of confounding variables should be conducted.

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Introduction

Root canal sealers play a crucial role in the long-term success of endodontic treatment. Undeniably, core obturation material itself cannot fill the entire three-dimensional canal space due to the presence of lateral canals, accessory canals, canal irregularities and minor discrepancies that exist between root dentinal walls and the obturating material (1, 2). To achieve a hermetic and fluid-tight seal, endodontic sealers are used to seal off voids in the root canal systems (3, 4). A well-obturated root canal system can prevent bacteria reinvasion and their antibacterial activity significantly reduces the number of bacteria remaining in the canals which in turn provides a predictable success in endodontic treatment (5). Furthermore, the penetration of sealers into chemo-mechanically prepared root canals is of utmost importance for maximising the adaptability and sealing ability of the root canal filling (6, 7).

In the past decades, various root canal sealers have been constantly developed and marketed based on their major constituents, including zinc oxide eugenol, glass ionomer, epoxy resin, methacrylate resin, calcium hydroxide, silicone, and bioceramic-based root canal sealers (8). Recently, bioceramic-based root canal sealers have received considerable attention in the practice of endodontics. Bioceramics in endodontics was first introduced by Torabinejad in the 1990s (9), of which mineral trioxide aggregates (MTA) is a ceramic cement based on the hydraulic powders of tricalcium silicate and dicalcium silicate. Bioceramic-based endodontic sealers can be further classified into calcium silicate-based (iRoot SP, EndoSequence BC Sealer), MTA-based (MTA Fillapex, Endo CPM Sealer, ProRoot Endo Sealer), and calcium phosphate-based (iRootSP and EndoSequence BC, Bio-C Sealer) (10). They exhibit several advantages such as having an alkaline pH, effective antibacterial ability, biocompatibility, no shrinkage and are chemically stable in the biological milieu (11).

With the emerging use of bioceramics in endodontics, numerous studies have been conducted to assess the material's performance as a root canal sealer. The ability to provide a good seal by means of dentinal tubule penetration is one of the most widely used methods for monitoring the effectiveness of these biomaterials in endodontic applications. Root canal sealers can penetrate into the dentinal tubules, forming a physical barrier, enhancing root filling retention, and encasing residual microorganisms (12). It has also been suggested that if a sealer can penetrate the tubules far enough, it will have a greater antibacterial effect (13). Nonetheless, the depth and consistency of the sealer penetration into root dentine tubules are influenced by physical and chemical parameters such as particle size, solubility, viscosity, and surface tension (12).

To the best of the authors' knowledge, there is still no unanimity in the literature when comparing the dentinal tubule penetration of bioceramic-based sealers to other types of sealers (14-17). Data and findings from related research topics can be summarised and contrasted through systematic review and meta-analysis, offering the highest level of clinical evidence to assist clinicians in obtaining the information they require (18). In addition, the authors also questioned whether bioceramic-based root canal sealers can achieve better dentinal tubule penetration than epoxy resin-based sealers. Hence, the current review aimed to answer the critique and comprehensively compare and evaluate the dentinal tubule penetration of bioceramic and epoxy resin-based root canal sealers.

Review

Protocol and registration

The current systematic review was carried out according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) protocol (19), and it was registered in the Prospective Register of Systematic Reviews (PROSPERO), University of York, with the registration number, CRD42021275860. The focused question was formulated using the PICOS

framework, which includes the Population (P), Intervention (I), Comparison (C), Outcome (O), and Study design (S).
The PICOS criteria were: (P) Root canal treated teeth, (I): Bioceramic-based root canal sealers, (C) Epoxy resin-based root canal sealers, (O) Dentinal tubule penetration, and (S) *in-vitro* experimental studies. Therefore, the PICOS question was "Do bioceramic-based root canal sealers have greater dentinal tubule penetration in root canal treated teeth than epoxy resin-based root canal sealers?". In this context, bioceramic sealers include calcium silicate-based, mineral trioxide aggregate-based, and calcium phosphate-based materials (10).

Search strategy
Four investigators (JZL, DZKC, IZK, WMX) used seven online databases to search for articles published between January 1990 and March 2022 (Google Scholar, PubMed, Web of Science – Core Collection, Scopus, Cochrane Library, EBSCO, and Open Grey). Two other investigators (GSSL, VT) independently reviewed the reference lists of relevant papers from the electronic search and keyed into a computer software (EndNote X9, Thomson Reuters). Deduplication of articles was accomplished using the software, and the titles of the remaining articles were recorded for the next screening stage. The keywords used for each database are 'dentinal tubule penetration', 'dentine tubule penetration', 'dentinal tubular penetration', 'dentine tubular penetration', 'dentine penetration', 'dentinal penetration', 'calcium silicate', 'calcium phosphate', 'bioceramic', 'mineral trioxide aggregate', 'MTA', 'root canal sealer' and 'endodontic sealer'. During the search, the Boolean operators 'AND' and 'OR' were employed to combine these keywords.

Study selection
Following the removal of duplicate publications, two investigators (JZL and DZKC) independently filtered the studies based on the title and abstract. Subsequently, another two investigators (IZK, WMX) conducted a thorough full-text assessment based on the inclusion and exclusion criteria. The inclusion criteria in choosing the articles are:

- Bioceramic-based and epoxy resin-based root canal sealers
- Studies evaluating the sealer penetration to root dentinal tubules
- In-vitro studies using extracted teeth

The exclusion criteria are:

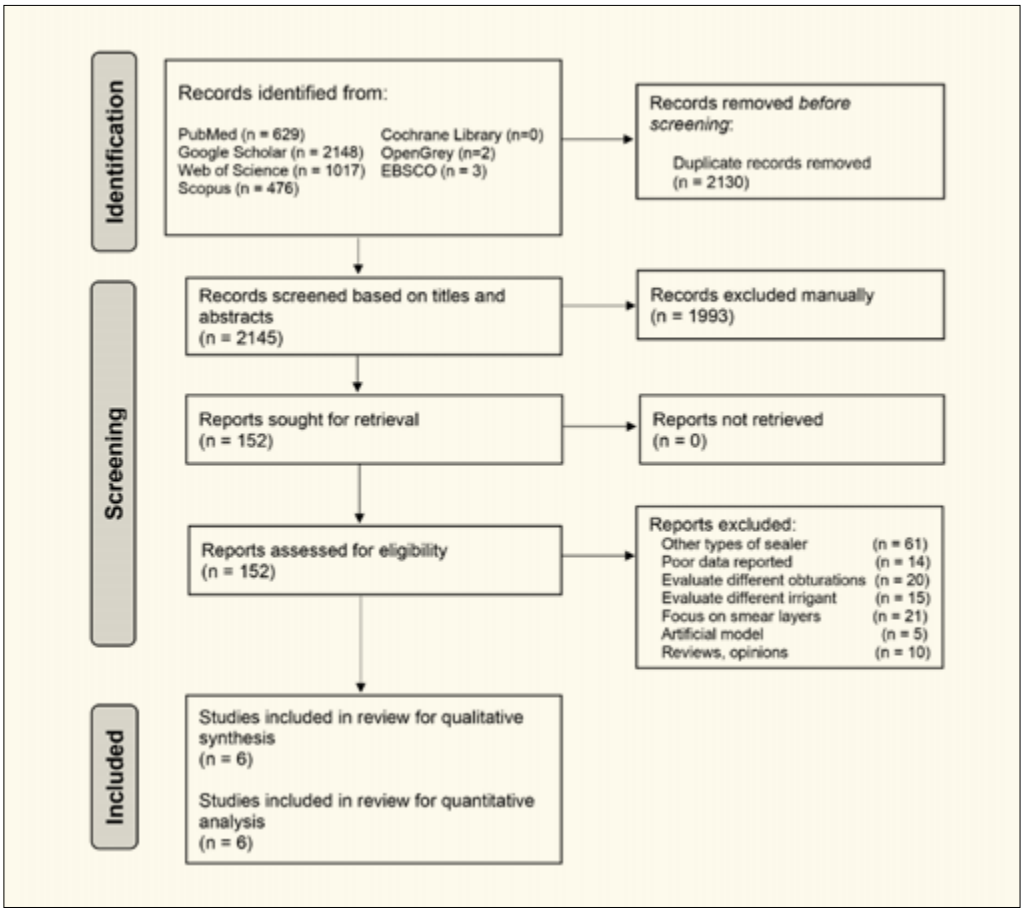
- Other types of root canal sealer (zinc oxide eugenol-based, calcium hydroxide-based etc.)
- Using artificial tooth model
- Heat obturation (warm gutta-percha obturation etc.)
- Animal studies, prospective or retrospective studies, randomised or non-randomised controlled trials, expert opinions, reviews, case reports and case series
- Poor data reported - No mean and standard deviation of the sealer penetration depths
- Experiments that focused on different obturation techniques, irrigating solutions, and smear layer removal

Calibrations between investigators were performed to assess interrater reliability. The average concordance was determined using the Kappa value to compare the investigators' decisions on inclusion and exclusion (20). Any conflicts that arose throughout the search were addressed and resolved with the assistance of the fifth investigator (GSSL).

Data extraction
The following variables were extracted from each article using a customised Google Spreadsheet form to aid comparability: authors, year of publication, type of study, sample size, tooth type, types of final irrigation, types of sealers, mechanical instrumentation, storage condition, thickness of sample, tubule penetration assessment tool, area of testing, obturation technique and the general results. One investigator (GSSL) double-checked the data's accuracy, and any disputes were settled by consensus among all authors.

Risk of bias assessment
The risk of bias (RoB) for each included study was assessed using the Office of

Figure 1
The PRISMA flowchart search strategy.



Health Assessment and Translation (OHAT) Risk of Bias Assessment Tool from the National Toxicology Programme (NTP) (21). The OHAT assessment tool was also modified to account for *in-vitro* experimental study designs. A list of ten domains was used to identify potential bias, and a supplementary category for 'other potential threats to internal validity'. However, only questions 1, 2, 5, 6, 7, 8, 9, 10 and 11 were applied to evaluate experimental studies. The 11th question labelled 'other bias' by OHAT, allows for the incorporation of other possible risks to internal validity (e.g., statistical methods). Each RoB question was addressed on a four-point scale: 'definitely high (DH)', 'probably high (PH)', 'probably low (PL)', and 'definitely low (DL)'. 'NR' was assigned when insufficient information can be retrieved or not reported from the selected study. The assessments were completed independently by two investigators (JZL, DZKC). Any differences were also resolved by discussion with the third investigator (GSSL).

Statistical Analysis

After evaluation, all the included studies were deemed eligible for quantitative analysis. Data were entered into the Cochrane Collaboration Review Manager software (RevMan5.4, The Cochrane Collaboration, Oxford, England) and statistical analysis was performed with the significance threshold set at P=0.05, whereas the confidence intervals (CI) set at 95%. A two-arm meta-analysis based on the DerSimonian-Laird random-effects model was used to assess the standardised weighted mean differences in dentinal tubule penetration (μm) of both bioceramic-based and epoxy resin-based root canal sealers. Due to limited data available, sealers from the same origin and root sections were pooled together (Appendix 1). The effect size was calculated based on the sample

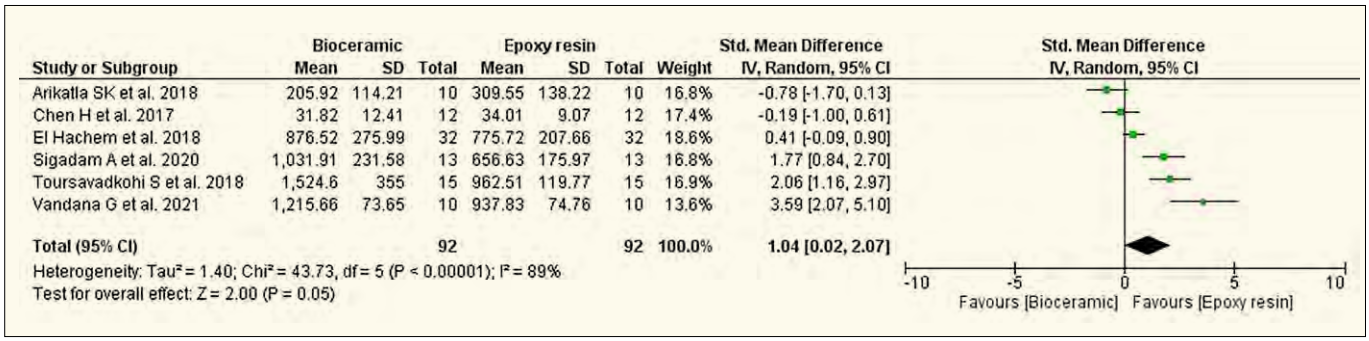


Figure 2
Two-arm meta-analysis showing the weighted mean differences of dentinal tubule penetration among bioceramic-based and epoxy resin-based sealers.

size for each study that included more than one group of bioceramic-based root canal sealers, and then pooled across the groups. Furthermore, studies that evaluated dentine tubule penetration at various root sections were pooled together to obtain the overall estimated mean values. The Higgins' I^2 statistic was also used to evaluate the degree of data heterogeneity across studies, with I^2<30%=acceptable heterogeneity, $I^2$30-60%=moderate heterogeneity, and I^2>60%=substantial heterogeneity (22). Subgroup analysis was conducted to assess the effect of obturation techniques and evaluation tools on the tubular penetration depth of root canal sealers. The publication bias was detected using Egger's test.

Review data

Study Selection

A total of 4,275 articles were identified during the initial search, with 2,130 duplicates being eliminated. Subsequently, 1,993 articles were excluded based on their titles and abstracts, while 146 articles were discarded based on the inclusion and exclusion criteria following full text assessment. Finally, only 6 articles were selected for qualitative and quantitative analyses. The average Kappa score for preliminary article screening (titles and abstracts) and the second screening (full-text assessment) was 0.73 and 0.70, respectively, indicating a 'strong' agreement (24). Figure 1 depicts the reasons for eliminating the articles.

Study Characteristics

Table 1 lists the characteristics of the included studies, all of which were published between 2017 and 2021 and employed an *in-vitro* experimental study design. Four studies used mandibular premolars (6, 23-25), while the other two used central incisors (7, 26). Except for Toursavadkohi S *et al.* (26), all the studies used crown down techniques during cleaning and shaping. Furthermore, only two studies used a single cone approach for obturation (7, 25), whereas the other four studies used lateral condensation approach.

Risk of bias assessment

Table 2 presents the risk of bias assessment using the OHAT critical appraisal tool. All included studies were assigned a 'DL' for domains 7, 8, 9, 10 and 11. Meanwhile, all the studies were given 'PH' for both domain 2 and domain 6 due to insufficient information establishing that samples were appropriately concealed and that the investigators were blinded during the experiments. On the other hand, Domains 1 and 5 were rated as either 'PL' or 'DL'.

Statistical Analysis

The mean and standard deviation of the dentinal tubule penetration (µm) of bioceramic and epoxy-resin based root canal sealers are shown in Table 2. Two-arm meta-analysis revealed that the overall standardised weighted mean difference of dentinal tubule penetration was 1.04 (95% CI: 0.02 to 2.07), with epoxy resin-based sealers demonstrating significantly deeper tubular penetration (P=0.05) compared to bioceramic-based sealers (Figure 2). The I^2 of the weighted mean differences of dentinal tubule penetration was 89%, implying that the included

Table 1
Characteristics of the selected studies

Author	Year	Type of studies	Sample size	Tooth type	Type of final irrigation	Type of sealers	Mechanical Instrumentation	Storage condition	Thickness of sample	Tubule penetration assessment tool	Area of testing	Obturation technique	General results
Arikatla SK et al.(23)	2018	In-vitro	30	Mandibular premolars	DW	AH Plus, MTA Plus, BioRoot RCS	Protaper rotary NiTi files up to F3	100% humidity at 37 °C for 1 week	n/a	CLSM	3 mm and 6 mm from root apex	LC	AH Plus sealer has shown significantly higher depth of penetration and minimum gaps than bioceramic sealers
Chen H et al.(24)	2017	In-vitro	50	Mandibular premolars	DW	RealSeal SE, AH Plus, iRoot SP, Cortisomol	Protaper rotary NiTi files up to F3	100% humidity at 37 °C for 10 days	n/a	SEM	2, 5, and 8 mm from root apex	LC	Maximum penetration was exhibited by RealSeal SE, followed by AH-Plus, iRoot SP, and Cortisomol
Vandana G et al.(25)	2021	In-vitro	20	Mandibular premolars	DW	AH Plus, EndoSequence BC	Protaper rotary NiTi files up to F3	100% relative humidity at 37 °C for 24 hours	1 mm	CLSM	3, 6, and 9 mm from root apex	SC	EndoSequence BC showed more depth of penetration than AH Plus.
Toursavadkohi S et al.(26)	2018	In vitro	50	Central incisors	DW	AH 26, Easy-Seal, Sure-Seal	Step-back with a #40 master apical file	incubated for 2 weeks	1 mm	SEM	3 and 6 mm from root apex	LC	Tubular penetration of AH 26 sealer is less than that of Easy-Seal and Sure-Seal at 3-mm and 6-mm sections.
El Hachem et al.(7)	2018	In-vitro	96	Maxillary central incisors	DW	EndoSequence BC, AH Plus, NTS	Protaper rotary NiTi files up to F4	37 °C at 100% humidity for 2 weeks	2 mm	CLSM	1 mm and 5 mm from root apex	SC	BC Sealer and NTS demonstrated better tubule penetration results than the AH Plus sealer.
Sigadam A et al.(6)	2020	In-vitro	65	Mandibular premolars	DW	Endomethasone, AH-Plus, Roekoseal, MTA Fillapex, EndoSequence BC	Protaper rotary NiTi files up to F4	n/a	1 mm	CLSM	Coronal, middle, and apical 1/3	LC	EndoSequence BC showed the highest penetration into dentinal tubules.

n/a: not available; DW: Distilled water; CLSM: Confocal laser scanning microscope; SEM: Scanning electron microscope; LC: Lateral condensation; SC: Single cone

studies for quantitative analysis had significant heterogeneity. Sensitivity analysis (Appendix 2) was performed, and the largest and smallest weighted mean differences of dentinal tubule penetration were 250.79µm [CI: (59.68, 441.90)] and 122.00µm [CI: (-27.29, 271.29)] when Arikatla SK *et al.* (23) and Toursavadkohi *et al.* (26) were excluded, respectively. Subgroup analyses were conducted to evaluate different obturation techniques and evaluation tools on the dentinal tubule penetrations of root canal sealers (Appendix 3). No significant difference in tubular penetration depth was found when compared between single cone and lateral compaction obturation techniques (P=0.147). Nevertheless, there was a significant difference (P=0.018) in the evaluation tools, with the scanning electron microscope demonstrating greater tubular penetration than the confocal microscope. The effect of the sample sizes of each study on the dentinal tubule penetration depth was evaluated using meta-regression. There was no statistically significant difference (P=0.611), indicating that the sample size of each study had no direct effect on the degree of data heterogeneity. Egger's test using funnel plot (Figure 3) suggested that no evidence of significant publication bias was observed (P=0.06), with a fairly equal distribution of included studies on each side of the line.

Conclusions

The present systematic review and meta-analysis aimed to comprehensively

Table 2

Evidence table on the mean and standard deviation of the dentinal tubule penetration (µm) of bioceramic and epoxy-resin based root canal sealers with the risk of bias of each included study based on JBI risk of bias assessment tool

Study	Year	Sample per group	Sealers		Dentine Tubule Penetration (mean ± SD)		Obturation Technique	Evaluation Tool	RoB (Domain)								
			Bioceramic-based	Epoxy resin-based	Bioceramic-based	Epoxy resin-based			1	2	5	6	7	8	9	10	11
Arikatla SK et al.(23)	2018	10	MTA Plus, BioRoot RCS	AH Plus	205.92 (114.21)	309.55 (138.22)	LC	CLSM	DL	PH	DL	PH	DL	DL	DL	DL	DL
Chen H et al.(24)	2017	12	iRoot SP	AH Plus	31.82 (12.41)	34.01 (9.07)	LC	SEM	DL	PH	DL	PH	DL	DL	DL	DL	DL
Vandana G et al.(25)	2021	10	EndoSequence BC	AH Plus	1215.66 (73.65)	937.83 (74.76)	SC	CLSM	PL	PH	PL	PH	DL	DL	DL	DL	DL
Toursavadkohi S et al.(26)	2018	15	Sure-Seal	AH 26	1524.60 (355.00)	962.51 (119.77)	LC	SEM	PL	PH	PL	PH	DL	DL	DL	DL	DL
El Hachem et al.(7)	2018	32	EndoSequence BC	AH Plus	876.52 (275.99)	775.72 (207.66)	SC	CLSM	PL	PH	DL	PH	DL	DL	DL	DL	DL
Sigadam A et al.(6)	2020	13	EndoSequence BC	AH Plus	1031.91 (231.58)	656.63 (175.97)	LC	CLSM	DL	PH	DL	PH	DL	DL	DL	DL	DL

SD: standard deviation; LC: lateral condensation; SC: single cone; CLSM: confocal laser scanning microscopy; SEM: scanning electron microscopy; DH: definitely high; PH: probably high; PL: probably low; DL: definitely low.
Domain 1: Was administered dose or exposure level adequately randomized?
Domain 2: Was allocation to study groups adequately concealed?
Domain 5: Were experimental conditions identical across study groups?
Domain 6: Were research personnel blinded to the study group during the study?
Domain 7: Were outcome data complete without attrition or exclusion from analysis?
Domain 8: Can we be confident in the exposure characterization?
Domain 9: Can we be confident in the outcome assessment (including blinding of assessors)?
Domain 10: Were all measured outcomes reported?
Domain 11: Were there no other potential threats to internal validity (statistical method)?

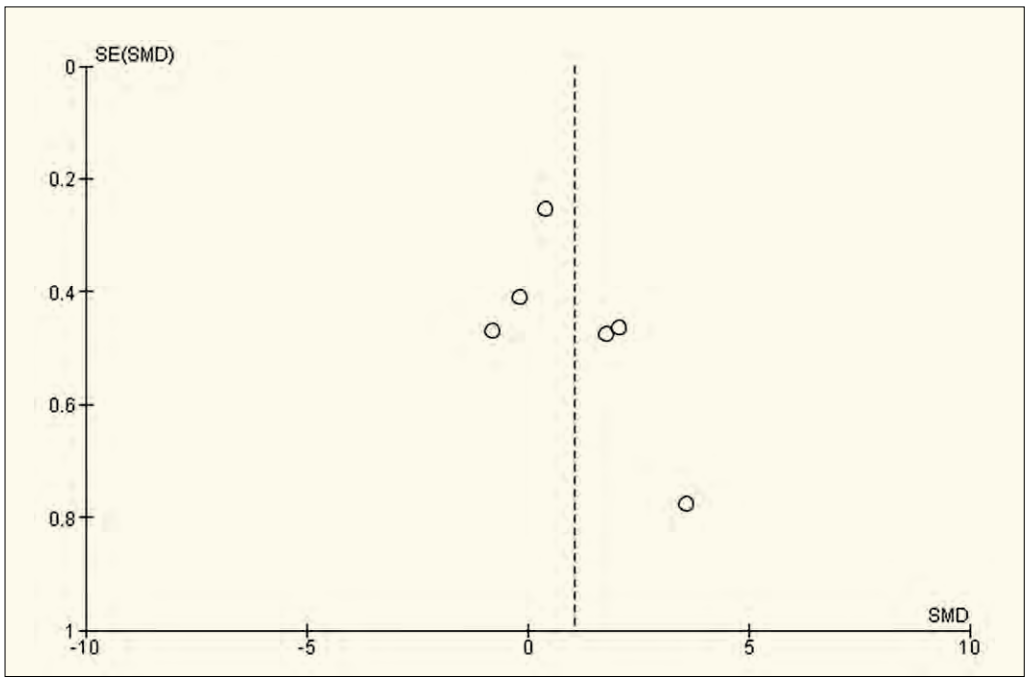


Figure 3
Funnel plot of dentinal tubule penetration among bioceramic-based and epoxy resin-based root canal sealers.

evaluate the dentinal tubule penetration of bioceramic-based root canal sealers as compared to epoxy resin-based sealers in order to provide valuable insight with reliable evidence-based findings. An excellent adaptation of filling materials to the root canal walls is required for optimal obturation which can be achieved by solidly compacting gutta-percha and sealer into a homogeneous mass (17). The creation of sealer tags into dentinal tubules may also aid in the adaptation and retention of filling material to the root dentinal wall (27). Based on the current two-arm meta-analysis, epoxy resin-based sealers showed a significantly deeper dentinal tubule penetration than bioceramic-based sealers.

The epoxy resin-based sealer used among all included primary studies was AH Plus, except for one study that used AH 26 (26). AH Plus is extensively utilised due to its physicochemical properties, simplicity of handling, and frequent use as a "gold standard" or control in several studies (7, 28, 29). The strong covalent bonds between the amino group of root dentine and the epoxy ring of resin can form micro-mechanical lock within the root dentinal walls, leading to a high bond strength of epoxy resin-based sealer (8). Several studies have found that an epoxy resin-based sealer possesses superior tubular penetration due to its high flow rate and capillary action in the dentinal tubules, permitting the sealer to be drawn into the tubules rather than by hydraulic forces induced during root canal filling (23, 24, 30, 31). However, one should highlight that epoxy-resin based sealers are hydrophobic and will shrink due to polymerisation. It was also reported that the penetration depth of epoxy resin–based sealers could have been restricted due to residual moisture in the root canal after drying (32). Hence, it is still conceivable to state that the epoxy resin-based sealer's capacity to penetrate and adapt to dentinal walls may be hampered by moisture in the root canals (33). Therefore, future studies should emphasise the manipulation of epoxy-based resin matrix to enhance its hydrophilic characteristic and reduce shrinkage.

On the other hand, bioceramic-based sealers were claimed to exhibit smaller particle size, greater fluidity, and hydrophilicity which allow them to form more sealer tags when in contact with the dentinal walls, resulting in greater sealer penetration and adaptation (27, 34). Bioceramic-based sealers have also been discovered to show high hydraulic conductivity which can form tag-like structure 'mineral infiltration zone' and obstruct dentinal tubules (1), allowing for greater bond strength and tubular penetration (35). However, such scientific theories contradict the current findings, which could be due to the methodology design, since most included studies kept the samples at 100% humidity, leading to increase the solubility of bioceramic-based sealers over epoxy resin-based sealers (36). One technique to improve the sealing capacity and tubular penetration of bioceramic-based sealers is the employment of ultrasonic activation during root canal obturation which can increase the flowability of the sealer materials (37, 38). Furthermore, the mixing procedure of root canal sealers could be a critical aspect in dentinal tubule penetration. Premixed bioceramic-based sealers displayed higher tubular penetration than the conventional powder-liquid form when compared with epoxy resin-based sealers (27, 39). Additionally, inconsistencies in results across the literature may be attributable to differences in the size and number of dentinal tubules, and evaluating specific root sections may not be a reliable way to extrapolate sealer penetration throughout the root canals (31).

Scanning electron microscope (SEM) and confocal laser scanning microscope (CLSM) are both useful assessment tools to investigate and examine features such as surface topography, porosity, and particle size of dental materials, as well as the evaluation of dentinal tubule penetration of root canal sealers (7, 23, 40). Subgroup analysis in the present review showed that SEM demonstrated greater sensitivity in detecting tubular penetra-

tion compared to CLSM. This could be due to SEM's higher magnification level, which offers more detailed information, allowing investigators to appreciate dentinal tubules and the surface appearance of sealer materials, even when tubular density is low (17, 41). However, SEM possesses several drawbacks, including a lack of accurate identification at lower magnifications and the creation of artefacts during sample preparation for analysis (41). Furthermore, novice investigators may have difficulty interpreting SEM images since it is sometimes impossible to distinguish between the dentine and sealer present in canals due to the lack of fluorescent markers (42).

Conversely, CLSM allowed optical portions beneath the surface of dentine to be viewed without the need for special specimen processing such as removing the smear layer (34, 43). Moreover, CLSM creates fewer artefacts and does not cause dehydration of the sample. It also gives a thorough image of interfacial adaption and sealer dispersion using fluorescence, allowing for adequate analysis, due to its strong contrast (44). Thus, a standardised evaluation tool that can evaluate the three-dimensional tubular penetration is warranted in the future to allow better comparability among similar studies. The present results also revealed that no significant difference was observed when comparing dentinal tubular penetration using single cone versus lateral condensation technique, implying that the obturation technique utilised may not have a direct impact on sealer penetration in the root canal. Nevertheless, it should be noted that heat may have an adverse effect on the properties of most bioceramic-based sealers, notably their flowability, setting time, and adhesion to dentinal walls (45, 46). As a result, studies that employed heat obturation approaches were excluded from the current review to mitigate bias and offer a well-standardised meta-analysis.

The strength of the current review is that it adopts a systematic approach to evaluate the currently available studies on dentinal tubule penetration among bioceramic-based and epoxy resin-based root canal sealers. Despite this, clinical decision-making in providing definitive endodontic treatment remains challenging as direct extrapolation of the findings into clinical setting is not always practicable. Nevertheless, the current study also demonstrated several flaws. First, the results may be skewed due to the pooling of data from all three-thirds of the root regions. Previous studies have shown that maximum tubule penetration occurs in the root canal cervical third region, with a gradual decrease in the middle third and apical third (27, 34). This is mainly attributed to the histological characteristics of the apical root dentine, which include a high degree of sclerosis and poorly permeable dentinal structures with fewer dentinal tubules (30). Another factor to consider is the canal shape, which can range from round to oval (47). When employing the single cone obturation technique for oval-shaped canals, it has been advocated that auxiliary gutta-percha cones be used to enhance the hydraulic force in all directions and push the sealer into the tubules (48). Moreover, the number of primary studies eligible for inclusion in the current analysis is still limited, and pooling MTA and non-MTA bioceramic sealers could lead to bias since their element compositions varied despite similar classification.

The current review demonstrated greater dentinal tubule penetration among epoxy resin-based sealers as compared to bioceramic-based sealers. Besides, greater tubular penetration was observed using scanning electron microscope, but the type of obturation technique had no effect on the penetration depth. Future well-designed studies with standardised evaluation tools and more control of confounding variables should be conducted to provide more reliable results.

Clinical Relevance

Although bioceramic-based root canal sealers are considered a promising advancement in endodontics, the current systematic review revealed that bioce-

ramic sealers demonstrated inferior tubular penetration to root dentine walls as compared to epoxy resin-based sealers. Nevertheless, the current review paves the way for future research to establish a standardised experimental methodology and clarify the clinical outcomes of using these sealers.

Conflict of Interest

All authors declare no conflicts of interest.

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Not applicable.

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Lettera
DEL PRESIDENTE

Carissimi Soci, Amici e Colleghi,

negli ultimi tre anni siamo stati attori/spettatori di una fase davvero importante di crescita del Giornale Italiano di Endodonzia che ha portato finalmente a raccogliere i frutti che da tempo coltiviamo con impegno e duro lavoro. Da quando nel 2011 siamo passati al modello di rivista **Open Access** la nostra crescita non ha più conosciuto sosta. Aderire al modello open access ha permesso agli autori di rendere fruibili i risultati delle loro ricerche e al lettore di consultare gratuitamente gli articoli. Tutto questo è possibile grazie alla nostra Società che da sempre si fa carico di tutti i costi di pubblicazione. Questo aspetto potrebbe essere percepito come indicatore di un mediocre indice scientifico, invece incarna appieno la nostra mission istituzionale e a distanza di anni ha finalmente portato importanti risultati.
Tanti sono stati i cambiamenti per arrivare ad avere una rivista sempre più di respiro internazionale. Oggi possiamo affermare senza timore di smentita che il GIE è un fiore all'occhiello che molte altre Società, anche più importanti della nostra, ci invidiano.
Per poter crescere ancora dobbiamo avere la consapevolezza dei risultati che abbiamo raggiunto: l'obiettivo immediato è quello di far diventare il Giornale Italiano di Endodonzia un riferimento che ci deve far distinguere nel panorama delle riviste Open Access a livello nazionale e internazionale, diventando al tempo stesso uno strumento strategico che ci deve consentire di differenziarci dalla gran parte delle altre società scientifiche del settore.
Ricordo benissimo quando il nostro precedente editore ci ha lasciato per motivi legati a politiche editoriali interne proponendoci di fare una rivista simil bollettino societario con un editore estero associato. Come è facile capire la storia ha avuto un esito diverso. La scommessa era rischiosa ma oggi con immensa gioia e profondo orgoglio vi comunico che la nostra rivista continua a guadagnare posizioni nel panorama delle riviste odontoiatriche "indexate". Il Consiglio Direttivo è stato lungimirante e illuminato nel sostenermi in questo percorso ma gran parte del merito va all'Editore Ariesdue che ha sempre creduto in questo progetto proponendoci soluzioni pratiche e innovative che hanno portato risultati positivi fin da subito. Con immenso piacere vi comunico in questa mia ultima lettera del Presidente del GIE che la nostra rivista rientra a pieno titolo nell'elenco delle riviste indexate che nel prossimo anno dovrebbero ricevere un **Impact Factor**. Finalmente l'obiettivo da sempre più ambito sta per concretizzarsi!
Per questo motivo rinnovo l'invito al board e a tutti Soci di continuare a promuovere attivamente la rivista sottoponendo lavori originali, citando articoli del GIE su altri lavori scientifici, "portando" la rivista nei convegni in Italia e all'estero.
Non potevo concludere il mio mandato con una notizia migliore!
Attendiamo fiduciosi giugno 2023!

In attesa di rivedervi al IV Congresso Internazionale che si terrà a Bologna dal 3 al 5 Novembre colgo l'occasione per ringraziare il Consiglio Direttivo, tutte le Commissioni e i Soci che in questi due difficili anni hanno sostenuto la SIE, stando al mio fianco.

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Un caro saluto
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Riitano Dott. Francesco
Socio Onorario
Spina Dott. Vincenzo
Socio Onorario
Zerosi Prof. Carlo
Socio Onorario

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 Segreteria 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

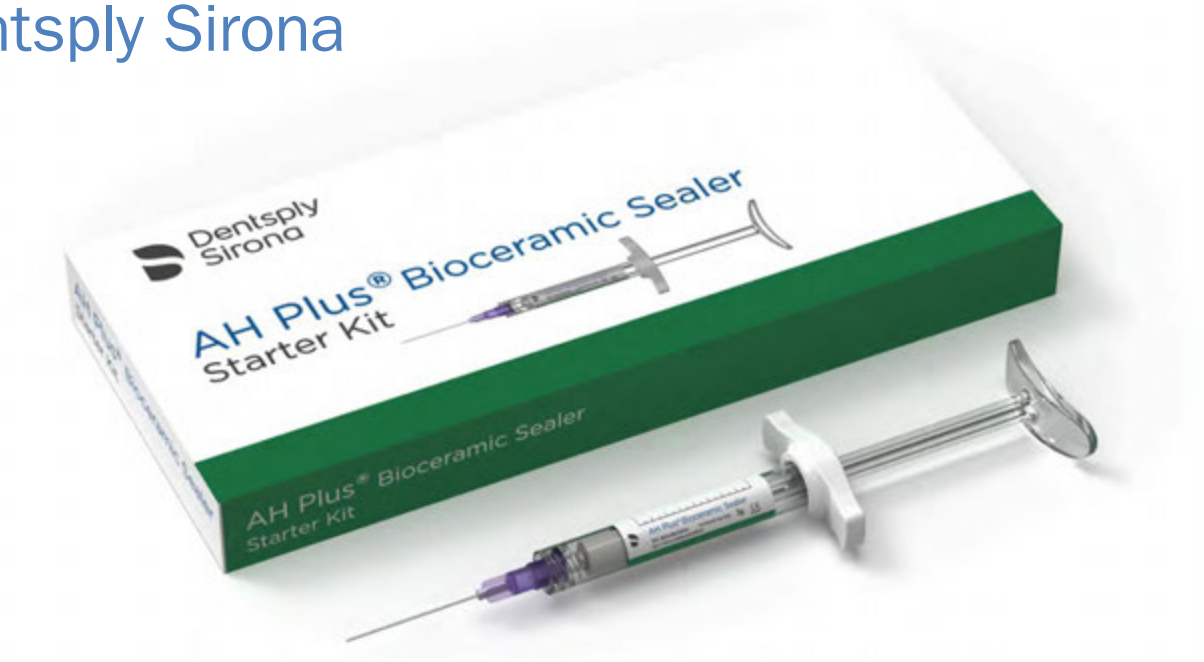
La CAS (Commissione Accettazione Soci) è formata cinque Membri di indiscussa esperienza clinica, quattro Soci Attivi con almeno cinque anni di anzianità in questo ruolo eletti a ogni scadenza elettorale dall'Assemblea dei Soci Attivi e Onorari e uno dei Past President della Società incaricato dal CD 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 2021-2022

Francesco Riccitiello (Past President della Società)
Maurizio Boschi
Marco Colla
Claudia Dettori
Giuseppe Multari

AH Plus Bioceramic Sealer

New bioceramic root canal sealer from Dentsply Sirona



Root canal sealers are used during the root canal obturation phase, which is the final step in root canal therapy. Root canal treatments often do not have a very high success rate. One of the major causes of root canal treatment failure is the persistence over time of microorganisms that cause infections in the endodontium: the role played by the filling is therefore extremely important. The endodontic obturation techniques aim to ensure a prolonged and stable seal through the root canal cements, which have the function of breaking down the microbial load present in the canal and preventing the spread of bacteria by occupying all the existing spaces. The endodontium, however, could be composed of a canal system with spaces that are difficult to access, which must in any case be filled evenly to ensure a successful filling.

Bioceramic materials contribute to the success of these critical phases of obturation thanks to their antimicrobial and sealing characteristics. Numerous clinical studies show that they are not only well tolerated by surrounding tissues, but their bioactivity also induces the natural self-healing process. Furthermore, being hydrophilic, they do not present complications in the event of humidity, like other resin-based sealers.

AH Plus Bioceramic Sealer creates an ideal environment for the formation of hydroxyapatite, the main mineral that makes up teeth and bones, thus paving the way for the natural self-healing process. The bioactivity is certainly very important, but it remains essential to ensure a stable seal. AH Plus Bioceramic Sealer stands out for its dimensional stability: the characteristics of smoothness and fluidity allow it to reach all spaces, while the low solubility of 0.11% and the high resistance to rinsing stabilize the root canal in the long term. This sealer also has better radiopacity than other bioceramics (7.5 mm/Al).

The product comes in syringes preloaded that do not require a specific manual mixing and can thus be inserted directly into the channel, guaranteeing time savings and less waste. They are therefore very comfortable and efficient for the clinician and less invasive for the patient.

AH Plus Bioceramic Sealer fits into Dentsply Sirona's endodontic solutions, such as ProTaper Ultimate and WaveOne Gold, two historical endodontic brands known and appreciated for decades by dentists around the world.

AH Plus Bioceramic Sealer is indicated by many clinicians as the future of root canal filling, as it represents a step towards a more reliable endodontics for the patient.

About Dentsply Sirona

Dentsply Sirona is the world's largest manufacturer of professional dental products and technologies, with over a century of innovation and service to the dental industry and patients worldwide. Dentsply Sirona develops, manufactures, and markets a comprehensive solution offering including dental and oral health products as well as other consumable medical devices under a strong portfolio of world class brands. Dentsply Sirona's products provide innovative, high-quality and effective solutions to advance patient care and deliver better and safer dental care.

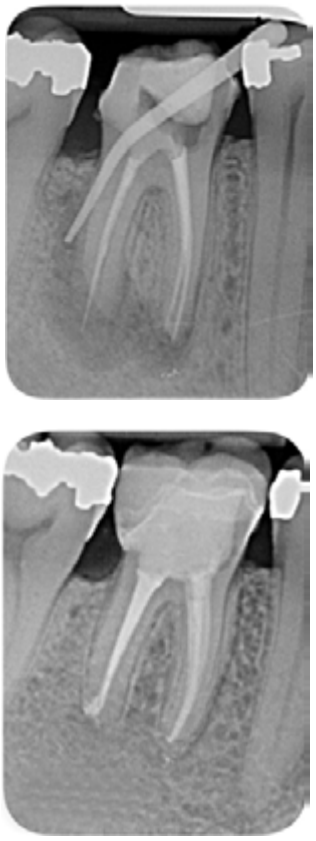
Visit **www.dentsplysirona.com** for more information about Dentsply Sirona and its products.

Visit **https://www.dentsplysirona.com/it-it/esplora/endodonzia/ah-plus-bioceramic-sealer.html** for AH Plus Bioceramic Sealer.

Dentsply Sirona

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.

sweden & martina

BLUESHAPER®

Il Sistema unico sul mercato con due diverse leghe per una sagomatura del canale semplice e veloce.

I nuovi strumenti BlueShaper® sono la 6ª generazione di NiTi file creati con una doppia lega PINK & BLUE che garantisce performance predicibili offrendo all'odontoiatra fiducia, velocità e sicurezza in tutte le situazioni che si affrontano quotidianamente.

BlueShaper®, in modo più efficiente e fluido, crea la forma conica del canale, apportando nuovi vantaggi: massima flessibilità e resistenza alla fatica ciclica, con un sistema di strumenti completo, senza modificare le abitudini di lavoro.

La doppia lega di BlueShaper® garantisce performance predicibili in quanto sviluppata da Odontoiatri per Odontoiatri.

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Sistema unico sul mercato con 2 leghe: rosa e blu

- La lega rosa, presente nello strumento Z1, conferisce una resistenza torsionale sufficiente per avanzare in qualsiasi canale, anche in canali stretti o calcificati.
- La lega blu, presente nel resto degli strumenti, aumenta la resistenza alla fatica ciclica per rispettare l'anatomia iniziale nei canali con forte curvatura.

Alta potenza di torque

BlueShaper® è un sistema altamente versatile.

Il suo «torque power» si adatta a tutti i tipi di canali, rispettando la dentina pericervicale e la morfologia del canale.

Movimento continuo

- Il movimento degli strumenti BlueShaper® è una rotazione continua.

Massima flessibilità

- Il sistema BlueShaper® ha una flessibilità extra per facilitare l'accesso a tutti i tipi di canali, anche ai molari superiori con aperture limitate.

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SIMIT NEXT
Endo Expert
Divisione Gruppo Simit Dental

EdgeEndo

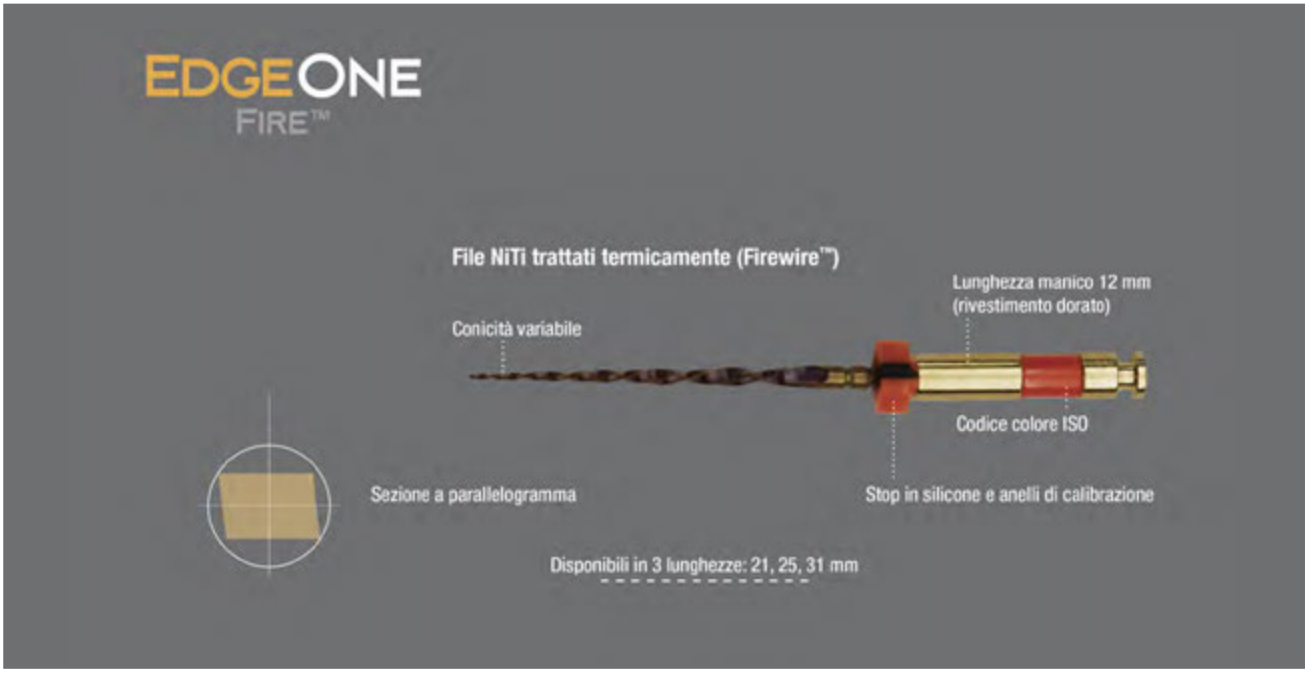
PERFORMANCE. PRICE. TECHNOLOGY.

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
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MORITA

Tr zx II

Il nuovo TR ZX II si presenta in un design innovativo e moderno. Come successore del motore Endo TRZX II con localizzatore apicale integrato, continua ad essere il solo sistema endodontico sul mercato che combina entrambe le funzioni in un manipolo.
Per le nuove funzioni automatiche OTR e OGP e il funzionamento intuitivo garantisce risultati assolutamente affidabili e sicuri, in ogni momento. In questo modo, TR ZX II rende il trattamento ancora più efficiente, sicuro e ripetibile !

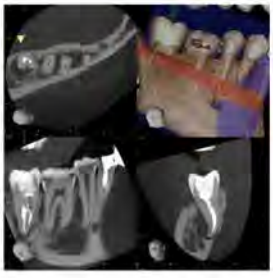
www.imoritaitalia.com

Veraview X800

La nuova generazione di raggi X mette in evidenza ogni minimo dettaglio con una risoluzione assoluta- mente nitida. Per la sua altissima risoluzione (voxel di 80 µm/2.5 LP mm) e per le sue funzioni innovative, questo innovativo sistema fornisce la base perfetta della certezza diagnostica Veraview X800 combina la qualità d'immagine ottimale con una bassa dose di radiazioni. Grazie alle funzioni scout, centrare un singolo elemento è un gioco da ragazzi, il software I-Dixel è semplice ed intuitivo. Funzione innovativa di Riduzione degli artefatti, funzione 360°, libreria impianti compresa.

11 FOV disponibili, da 4x4 fino a 15

Morita è riconosciuta in tutto il mondo per la sua grandissima qualità delle immagini e tu, sei il prossimo ad averla ?



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.

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);
VI. Name, full postal address, telephone, fax number and e-mail address of author responsible for correspondence (Corresponding Author).

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.

Abstract for Review Articles should be non-structured, no more than 250 words giving details of what was done including the literature search strategy.
Abstract for Mini Review Articles should be non-structured of no more than 250 words, including a clear research question, details of the literature search strategy and clear conclusions.
Abstract for Case Reports and **Case Series** should be no more than 250 words using the following structure:

- **Aim:** give a clear statement of the main aim of the report and the clinical problem which is addressed.
- **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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Abstract for Clinical Articles should be no more than 250 words using the following structure:

- **Aim:** give a clear statement of the main aim of the report and the clinical problem which is addressed.
- **Methodology:** describe the methods adopted.
- **Results:** give the main results of the study.
- **Conclusions:** state the primary conclusions of the study.

THE STRUCTURE

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Material and Methods must contain sufficient detail such that, in combination with the references cited, all clinical trials and experiments reported can be fully reproduced.
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Conclusions should contain a summary of the findings.

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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.

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Corporate author
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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