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GIORNALE ITALIANO DI ENDODONZIA

▸ Original articles

Root canal anatomy of mandibular incisors with Vertucci's type III configuration: a micro-CT evaluation

Physico-mechanical properties of two different heat treated Nickel-Titanium instruments: in-vitro study

Apical transportation and surface characteristics of thermally-treated reciprocating instruments after endodontic reintervention

Evaluation of extruded debris by different nickel titanium systems and hand files from apical foramen and simulated root perforation areas

Histopathology and immunohistochemical reactions of Nano-White MTA versus NeoMTATM Plus® and MTA Angelus® as immediate furcation perforation repair materials in a dog model

▸ Systematic Review

Apical debris extrusion and potential risk of endodontic flare-up: correlation with rotating and reciprocating instruments used in daily clinical practice

▸ Case Report

Treatment planning and therapy of a severely compromised two-rooted maxillary central incisor

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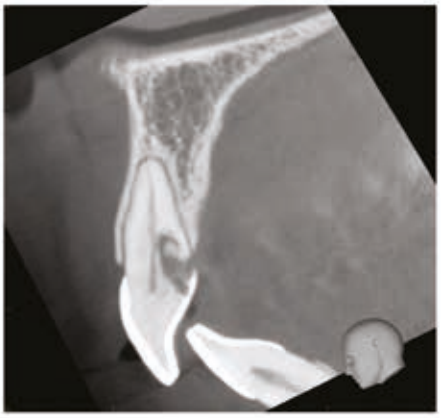

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Editorial

The modern management of endodontic complications

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Endodontic success depends on several factors, as anatomical complexity, proper disinfection and shaping of root canal system and sealability of filling. However, although the huge progress in materials and technology, there are still situations of difficult management that not only concern the failure of treatment, but also the side effects of endodontic therapy or the complications on root system because of external causes. In addition, it's noteworthy to stress that most of endodontic failures are due to inadequate knowledge of endodontic anatomy, that with its variability plays a fundamental role in unsuccess or occurrence of adverse effects. The importance of understanding root canals' anatomical complexity was already known in the early '900, as demonstrated by studies of several Authors such as Hass with his Tables and Vertucci with the introduction of his Classification. Even though the latter is nowadays considered a milestone, it's progressively been enriched by additional data provided by magnification and 3D technology. In this light, the present issue contains an article in which Vertucci's classification had been implemented by micro-ct. Moreover, are reported studies dealing with the use of new materials and innovative techniques to manage endodontic side effects as external root resorption, furcal perforation, post-treatment flare-up and pulp necrosis of immature permanent teeth due to trauma.

The proper treatment plan and the therapeutical management of complications play a pivotal role in endodontics and should represent a cultural background needed by clinicians operating in endodontic field. In this view, the Giornale Italiano di Endodonzia selects and encloses international peer-reviewed scientific papers that may be helpful in the permanent update of endodontic knowledge. Furthermore, from this year our mission is becoming wider with the release of 3 issues instead of 2.

In conclusion, it should be remembered and underlined that biological component is the main character in reaching endodontic success, despite of the products and technological progress, and it should be careful taken into account.

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ORIGINAL ARTICLE

Evaluation of extruded debris by different nickel titanium systems and hand files from apical foramen and simulated root perforation areas

ABSTRACT

Aim: *This study analyzed debris extrusion during canal preparation using different file systems for simulated root perforation areas and the apical foramen.*
Methodology: *One hundred thirty-five human mandibular premolars were divided into three main groups, each comprising 45 teeth (n=45), and these main groups were further subdivided into three subgroups, each consisting of 15 teeth (n=15). Group 1 served as the control with no perforations, while Groups 2 and 3 had 0.5-mm-diameter perforation areas created in the apical and middle 1/3 of the buccal root surfaces, respectively. The apical foramen was covered with two layers of nail polish in Groups 2 and 3. In each main group, canals were prepared with (a) hand files, (b) ProTaper Next (PTN: Dentsply Maillefer Ballaigues, Switzerland), and (c) WaveOne Gold (WOG: Dentsply Maillefer Ballaigues, Switzerland).*
Debris weights extruded from the apical foramen in Group 1 and from the perforation areas in Groups 2 and 3 were calculated. Groups were compared using a two-way ANOVA test.
Results: *The (a) hand file extruded significantly more debris than the (b) PTN and (c) WOG in Group 1* (P_{ab}<.001, P_{ac}<.001) *and Group 2* (P_{ab}=.004, P_{ac}=.005). *In Group 3, the a) hand file and the c) WOG file system caused a statistically higher amount of debris extrusion than the b) PTN file system* (P_{ab}=.006 *and* P_{cb}=.024). *During the root canal preparation, the most debris extruded from the apical foramen for hand files, from the apical 1/3 perforation for the PTN system, and from the middle 1/3 perforation for the WOG system.*
Conclusions: *Within the limitations of this study, it can be concluded that all the tested files and the location of the perforation area on the root surface influenced the debris extrusion.*

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KEYWORDS *Debris extrusion, NiTi file, root canal preparation, root perforation*

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Introduction

One of the crucial steps in endodontic treatment is the mechanical preparation of root canals (1). Endodontic file fracture, canal transportation, and root canal perforations are among the most common complications during this step (2-4). Perforation refers to the connection between the root canal and the external root surface, which may occur due to factors such as root resorption, radicular caries, or iatrogenic applications (5). During chemo-mechanical debridement, organic and inorganic debris, microorganisms, and irrigation solutions can be extruded into peri-radicular tissues through the apical foramen (6). However, it has been stated that the risk of extrusion should be considered during endodontic procedures due to the possibility of apical root resorption in teeth with apical periodontitis (7). Extrusion of debris during the mechanical preparation of root canals has been associated with post-operative pain and delayed periodontal healing due to the resulting inflammation (8, 9). The amount of extrusion varies depending on factors such as root canal morphology, irrigation technique, depth of irrigant penetration, working length (WL), apical foramen size, file design, preparation procedure, or motion kinematics (10-15).

Manufacturers continually develop new files or modify existing systems to facilitate root canal preparation, preserve the original shape of the canal anatomy, and prevent iatrogenic errors compared to stainless steel instruments.

Recently, ProTaper Next rotary files (PTN: Dentsply Maillefer Ballaigues, Switzerland) made of M-wire nickel-titanium (Ni-Ti) alloy have been produced using a thermal process to increase flexibility and cyclic fatigue resistance (16). WaveOne Gold systems (WOG; Dentsply Maillefer, Ballaigues, Switzerland) have been improved with gold heat processing and feature a new parallelogram shape with two cutting edges. WOG and PTN files both have an off-center design (17). According to the manufacturer, the Gold technology results in increased flexibility and cyclic fatigue resistance of the file. While there are numerous studies (11, 12, 18) on apical debris extrusion caused by various endodontic systems in the literature, none have focused on the effect of root perforations on debris extrusion.

The aim of this study was to assess the amount of debris extruding from root canals with simulated perforation and apical foramen during the preparation of root canals with PTN, WOG, and hand files. The null hypothesis was that the amount of debris extruded by file systems would not differ significantly depending on the apical foramen and perforation areas.

Materials and Methods

Sample selection

This ex vivo study was approved by the Clinical Research Ethics Committee of the Akdeniz University, Faculty of Medicine (05.05.2021 - 289). The sample size was determined by using the data of a prior study (12), which indicated that the sample size for each sub - group be at least 15, with a significance criterion of $\alpha = 0.05$ and power = 0.80. Freshly extracted 135 human mandibular premolar teeth with less than a 10° curvature angle and without immature apices, caries, resorption, calcification, fractures, or cracks were used (19). Radiographs from the mesiodistal and buccolingual aspects were taken before the start of the experiment phase to verify the existence of a single canal. All tooth crowns were partially cut using diamond burs under water cooling to achieve a standardized length of 18 ± 1 mm. The access cavities of teeth were opened with high-speed diamond round burs. The apical patency of the roots was examined with a #10 K-file (Golden Star Medical Co., Ltd. Guangdong, China) under an X20 dental operating microscope (Stemi 508, ZEISS Germany). The WL was determined by subtracting 1

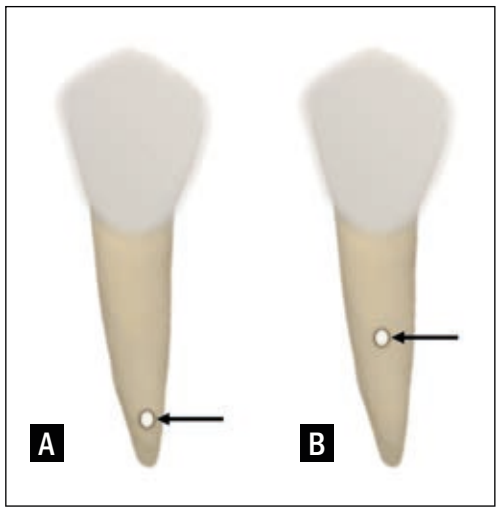

Figure 1
Perforations on the **A)** apical 1/3 and **B)** middle 1/3 of the buccal root surface of the teeth.

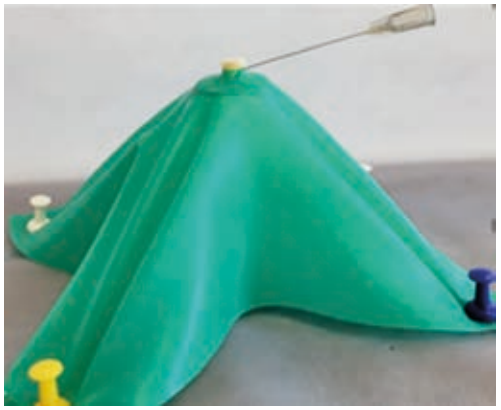

Figure 2
A modification of the experimental setup developed by Meyers and Montgomery was used for debris collection.

mm from the first length of each canal when the file tip reached the apical foramen under magnification. The #15 K-file was advanced to the WL, and the size of the minor constriction was checked. If the file extruded the apical foramen, the teeth were excluded. All the selected teeth were kept in the saline solution until used.

Creation of Perforations
The chosen teeth were randomly distributed into three main groups (*n:45*), and each main group was divided into three subgroups (*n:15*).
No perforation was created in the teeth in Group 1, and in this group, only the debris amount extruding from the apical foramen was examined. A perforation was created on the apical 1/3 and middle 1/3 of the buccal root surfaces of the teeth in Group 2 and Group 3, respectively (figure 1). Perforations were created using burs with a tip diameter of 0.5 mm. Whether the perforation area reached the root canal was examined and checked under a stereomicroscope. Then, the apical foramen was closed with two layers of nail polish in the Group 2 and 3. This enabled the creation of a closed-end canal model to evaluate the influence of the perforation area on debris extrusion.

Test Apparatus
A modification of the experimental setup developed by Meyers and Montgomery (20) was used to measure the amount of extruded debris. Due to the large amount of irrigation solution extruded from the perforation areas in the pilot study, extruded debris was collected in glass vials. The weights of empty glass vials were measured three times with an analytical balance (Shimadzu AP225WD, Kyoto, Japan) to an accuracy of 10^{-5} g, and the average value was recorded.
Holes were made on the stoppers of the glass vials, and the teeth were adapted to these holes. The needle (27-gauge) was positioned through the plastic stopper to balance the pressure in and out of the vials.
The glass vials were wrapped with aluminum foil to blind the operator, and the teeth were isolated with a rubber dam to avoid irrigation leakage through the hole. Figure 2 shows the setup of the experimental apparatus.

Root Canal Preparation and Evaluation of Debris Extrusion
For root canal preparation, the same procedures as explained below were used in all subgroups.

Preparation with the Hand Files (Group 1a, 2a, and 3a)
The canals were prepared using the step-back technique with #15-40 K-files (Golden Star Medical Co., Shenzhen, China). Apical preparations of the roots were conducted up to size 25 and then the step-back method was applied with a 1 mm decrease for each file until size 40.

Preparation with the PTN File System (Group 1b, 2b, and 3b)
In the PTN program, a Dentsply X-Smart Plus (Densply Maillefer, Ballaigues, Switzerland) endodontic motor with a torque of 2.0 N cm and a speed of 300 rpm was used, as the manufacturer's guidelines. PTN X1 file (17/0.04) (Dentsply Maillefer, Ballaigues, Switzerland) and then X2 file (25/0.06) were used in a brushing outstroke motion up to the WL.

Preparation with the WOG File System (Group 1c, 2c, and 3c)
The WOG Primary file (25/0.07) (Dentsply Maillefer, Ballaigues, Switzerland) was used in WOG ALL mode of Dentsply X-Smart Plus endodontic motor. The WOG Primary file was removed from the root canal after every three reciprocating movements (pecking motion) or when resistance was encountered, cleaned, and rinsed with distilled water. This procedure was continued until the WL was reached.
An operator conducted all the procedures. All teeth were irrigated with a total volume of 10 mL distilled water using a double-sided port needle (NaviTip 29-gauge; Ultradent South Jordan, UT, USA) positioned 2 mm short of the WL. Debris on the root surface of each tooth was rinsed with 1 ml of distilled water into a glass vial and collected. After that, the glass vials were placed in an incubator at 37 °C for 14 days to vaporize the solution. Then, all vials were weighed three times, as previously, and the average values were recorded. The weight of the debris was calculated by subtracting the vial's preoperative weight from its postoperative weight.

Statistical Analysis
The Shapiro-Wilk test showed that the values have a normal distribution, and the Levene test revealed that the data showed a homogeneous distribution. The effects of the files used and the areas where the debris extruded were examined with the two-way ANOVA test. Differences between groups were determined by pairwise comparisons with Bonferroni correction. Statistical tests were performed using SPSS Windows (SPSS for Windows, Version 22 SPSS, Inc., Chicago, IL, USA) software, and the significance was evaluated at the level of $P < 0.05$.

Results

Table 1 shows the average values with standard deviations (SD) of the weight of extruded debris for each test group.
Group 1 (Apical Foramen): the (a) hand file significantly extruded more debris compared to both (b) PTN and (c) WOG (Pab<.001, Pac<.001).
Group 2 (Apical 1/3 Perforation): Similar to Group 1, the (a) hand file produced significantly more debris than the (b) PTN and (c) WOG (Pab=.004, Pac =.005).
Group 3 (Middle 1/3 Perforation): in this group, (b) PTN extruded significantly less debris than (a) hand file and (c) WOG (Pba=.006, Pbc=.024). There was no statistically significant difference between (a) hand file and (c) WOG in terms of debris extrusion.
When examining the impact of each file system on the amount of debris extrusion from the apical foramen and perforation areas:
For preparation with (a) hand files, the highest amount of debris was extruded from the apical foramen (Group 1), and this amount exhibited a statistically significant difference when compared to the debris extrusion from the middle 1/3 perforation (Group 3) (P=.024).
For preparation with the (b) PTN System, the most debris was extruded from the perforation area in the apical 1/3 (Group 2), and this amount was statistically higher compared to the amount of debris extruding from the apical foramen (Group 1) (P=.001).
For preparation with the (c) WOG System, the most debris was extruded from the perforation area in the middle 1/3 of the root (Group 3), and the amount of debris extruding from this perforation area was statistically higher than the amount of debris extruding from the apical foramen (Group 1) (P=.035).

Table 1

Mean and SD values for the weight of extruded debris.

	Preparation Technique								
	(a) Hand file			(b) ProTaper Next			(c) WaveOne Gold		
	n	Mean	SD	*n*	Mean	SD	*n*	Mean	SD
Grup 1 (apical foramen)	15	.00187^{Aa}	.00082	*15*	.00040^{Ba}	.00020	*15*	.00078^{Ba}	.00028
Grup 2 (apical 1/3 perforation)	15	.00173^{Aab}	.00071	*15*	.00111^{Bb}	.00040	*15*	.00112^{Bab}	.00047
Grup 3 (middle 1/3 perforation)	15	.00135^{Ab}	.00066	*15*	.00075^{Bab}	.00023	*15*	.00126^{Ab}	.00056

In each column different lower-case letters show a statistically significant difference at the (0.05) level.
Different capital letters indicate a statistically significant difference at the (0.05) level in each row.

Discussion

Post-operative pain and swelling, which are undesirable complications for both the patient and the specialist, may occur because of debris extrusion during root canal preparation (21, 22). During endodontic treatment, the root canal contents, consisting of dentin chips, necrotic pulp tissues, and bacteria, can be pushed into the periapical region and trigger an inflammatory reaction (23). This ex vivo study investigated the amount of debris extruding from the apical foramen and the perforation areas created in the apical and middle 1/3 of the root surface during the preparation of root canals with two different NiTi file systems (WOG, PTN) and hand files.

The results indicated that there were significant differences in the amount of debris extruded by file systems from the apical foramen and perforation areas. Thus, the null hypothesis was rejected.

Numerous studies assessing the amount of debris extruded apically demonstrated that hand files extrude more debris than multi-file rotary systems and reciprocating single-file systems (11, 24, 25). Consistent with these finding, in current study, in all groups, hand file preparation resulted in the highest amount of extruded debris. Additionally, in Group 3 (middle 1/3 perforation), no statistically significant difference was found between WOG and hand file preparation in terms of the amount of extruded debris. During hand file preparation, the most debris extruded from the apical foramen, followed by the perforations in the apical 1/3 and middle 1/3. This can be attributed to the hand files' push-pull filing motion, akin to a piston, and the limited space between the file and dentinal walls, hindering the coronal transport of debris. Koçak et al. and Çakıcı et al. (26, 27) compared the amount of debris extrusion from the apical foramen using the PTG, Reciproc, PTN and PTU file systems, and found that the PTN file system caused significantly less extrusion. Similarly, our data indicated that PTN resulted in the least debris extrusion in all groups, with no statistically significant difference between PTN and WOG in Groups 1 (apical foramen) and 2 (apical 1/3 perforation).

During the preparation with PTN, the most debris extruded from the perforation in the apical 1/3, the perforation in the middle 1/3, and the apical foramen, respectively. The observed extrusion can be linked to the standardized closure of the apical foramen with two layers of nail polish and the continuous increase in taper of the X1 and X2 files up to 9 mm,

which could lead to debris being trapped in the dentin walls. Additionally, the brushing motions during the procedure may have contributed to higher debris extrusion, particularly in the apical 1/3. Eliasz et al. (18) reported no statistically significant difference in debris extrusion between PTN, WOG, and Twisted Files. Similarly, in our present study, no statistical difference in extruded debris was found between PTN and WOG in Groups 1 and 2. However, in Group 3, the WOG and hand file preparations resulted in statistically higher debris extrusion compared to the PTN. The WOG file system exhibited the least debris extrusion from the apical foramen but the highest amount of debris from the middle 1/3 perforation area, and these differences were statistically significant. This outcome can be attributed to the WOG system's pecking action, limited dentin contact at 1 or 2 points due to its cross-sectional design, and the presence of ample space for coronal debris transport, thanks to its decreasing taper towards the coronal part.

In previous studies, researchers usually created perforation cavities on root surfaces using diamond or carbide burs, and the diameters of the simulated perforation cavities in these studies ranged from 0.25 to 1.5 mm (28-30).

Topçuoğlu et al. (7) created a simulated external resorption area by horizontally removing the 2 mm apical part of the root with a fissure drill after completing root canal filling in a mandibular premolar tooth. They then evaluated the amount of debris extruding from the apical area during the retreatment process. On the other hand, Silveira et al. (31) developed a demineralization protocol using solutions of nitric acid and sodium hypochlorite (NaOCl) to simulate internal root resorption.

This approach resulted in resorption cavities with varying diameters and depths, making standardization challenging. In our study, we created perforations with burs featuring a 0.5 mm tip diameter to ensure standardization. Additionally, before the prepation procedures, the apices of all roots in Groups 2 and 3 were sealed with two layers of nail polish to simulate a closed-end canal model, as previously described (32, 33). The use of different file systems and techniques may lead to changes in the results of debris extrusion studies (6, 26).

There is no study in the literature investigating the effect of various file systems on the amount of debris extruded from the perforations created on the root surface. As a result, no direct comparison with other studies was possible.

It's important to acknowledge that studies investigating debris and irrigating solution extrusion using extracted teeth have inherent limitations. In vivo, the periodontal tissue surrounding the apical foramen offers natural resistance to debris extrusion. While attempts have been made to simulate this resistance using materials like floral foam and agar gel, these methods have been associated with certain challenges, including the absorption of irrigants by foam and the difficulty in precisely determining the agar gel thickness at the apex to replicate the size of the apical lesion (34, 35). Therefore, we opted not to use an apical barrier. Another critical consideration is the choice of irrigation solution, which can significantly impact study outcomes (36). The formation of crystals due to the use of sodium hypochlorite (NaOCl) may affect the amount of extruded debris. To mitigate this potential influence, we selected distilled water as the irrigation solution. Within the limitations of this research, all the file systems used in root canal preparation led to varying amount of debris extrusion from both the apical foramen and perforation areas. To gain a comprehensive understanding of the impact of debris extrusion from perforation areas on the success of endodontic treatment, further investigations, both *in vitro* and *in vivo*, will be necessary.

Conclusions

All the instruments used caused the debris extrusion. Hand files exhibited the highest amount of extruded debris in all tested groups. Careful selection of instru-

ments and techniques during endodontic procedures, especially in cases involving perforations, can significantly reduce debris extrusion and improve patient comfort and post-operative results.

Clinical Relevance

This study underscores the critical role of instrument choice in reducing complications, improving treatment success, and enhancing patient comfort during root canal procedures. Insights into the impact of various file systems and perforation sites on debris extrusion offer valuable guidance to clinicians. Furthermore, the study advocates for future research to optimize endodontic procedures, aiming for better overall clinical outcomes.

Conflict of Interest

The authors declare that they have no conflict of interest.

Acknowledgements

None.

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ORIGINAL ARTICLE

Histopathology and immunohistochemical reactions of Nano-White MTA versus NeoMTA™ Plus® and MTA Angelus® as immediate furcation perforation repair materials in a dog model

ABSTRACT

Aim: *This study compared histopathology and immunohistochemical reactions of Nano-white mineral trioxide aggregate (Nano-WMTA), Neo-mineral trioxide aggregate plus (NeoMTA™ Plus®), and mineral trioxide aggregate angelus (MTA Angelus®) as furcation perforation repair materials.*

Methodology: *Twelve premolars were used in six mongrel dogs. Seventy two teeth were divided according to post-treatment evaluation period into two main equal groups (three dogs' each/36 teeth each) including; group I: after one month and group II: after three months. Each main group was subdivided into three experimental subgroups (8 teeth each) according to the immediate perforation repair materials used, and two control groups. The perforations in subgroups 1, 2 and 3 were sealed with NeoMTATM Plus®, Nano-WMTA and MTA Angelus®, respectively. In the positive control subgroup (8 teeth), the perforations were done with no repair. Negative control subgroup (4 teeth) represented intact teeth with no perforation to show the normal histology. Pulpotomy and root canal obturation were carried out in the experimental and positive control subgroups. Inflammatory cell count and new hard tissue formation were evaluated by histopathology and immunohistochemical staining with Osteonectin. All data were statistically analyzed.*

Results: *All tested materials demonstrated significant lower inflammatory cell counts than the positive control subgroup and significant higher new bone formation than both positive and negative subgroups. There was no statistically significant difference in inflammatory cell count and new hard tissue formation among the experimental materials in both groups ($p<0.05$).*

Conclusion: *All tested materials effectively reduced inflammation and promoted hard tissue formation with no statistically significant difference.*

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Introduction

Root perforations are one of the problems that pose obstacles to successful endodontic therapy in endodontic practice (1, 2). Perforation repair prognosis is determined by its location, size, timeliness of repair, contamination, and biocompatibility of repair material (3, 4). Quick and successful perforation sealing is critical for tooth preservation, necessitating particular features in repair materials such as biocompatibility, bioactivity, non-toxicity, insolubility, radiopacity, and sealing capability (5, 6).

Mineral trioxide aggregate (MTA) and hydraulic calcium silicates are innovative dental materials with distinct properties that make them ideal for endodontic use. One of their distinguishing characteristics is their exceptional bioactivity, which means they can interact with the surrounding biological environment. This bioactivity promotes the regeneration of dental hard tissues such as dentin, making them useful for operations such as perforation repair and pulp capping (7, 8).

Furthermore, MTA and hydraulic calcium silicates have good antibacterial characteristics, inhibiting bacterial growth and reducing the risk of infection within the treated root canal (7, 9). These materials stand out due to their dual action of bioactivity and antibacterial impact, which promotes not only the structural integrity of the tooth but also the overall health of the dental tissues. MTA and hydraulic calcium silicates are indispensable in modern endodontics due to these properties, which contribute to the success and longevity of numerous dental operations (7-9).

Various materials have been used for perforation repair, MTA being a common choice due to its superior sealing and biocompatibility, albeit with drawbacks like long setting time and cost (10-12).

Neo MTA™ Plus® and Nano-White MTA have recently developed as modified alternatives with improved features such as faster setting, increased biocompatibility, and less discoloration problems (13, 14). NeoMTA™ Plus® is a modified and enhanced type of MTA that is used in endodontics to heal perforations. Its unique composition includes tricalcium silicate, dicalcium silicate, calcium aluminate, calcium sulfate, calcium hydroxide, and zirconium oxide, which enhances its handling properties and overall performance compared to traditional MTA (13-15). In comparison to MTA, NeoMTA™ Plus® has a significantly faster setting time, minimizing chair time and enhancing procedure efficiency. It has the same biocompatibility and tissue response characteristics as MTA but outperforms it in terms of handling, setting time, washout resistance, and overall formulation (14, 15). Because of these characteristics, NeoMTA™ Plus® is a favored choice for many doctors in endodontic procedures where speedy and effective perforation healing is critical for good outcomes (13-15).

Nano-White MTA is improved MTA cement used in endodontics to heal root perforations. It is distinguished by its nanoscale particle size, which allows for greater adaptability to uneven sites and facilitates a tight seal (16, 17). Furthermore, the nanoscale particles improve tissue contact, allowing the creation of a physiologically active dentin bridge and promoting spontaneous regeneration (16). Nano-White MTA uses nanotechnology to improve sealing and regenerative capacities, resulting in better results in root perforation repair and other endodontic operations (16, 17).

These materials are still being researched and developed in order to improve their properties and increase their applications in endodontic treatment. Therefore, this study compared the histopathological and immunohistochemical reactions of Nano-White MTA versus NeoMTA™ Plus® and MTA Angelus® as root repair materials in a dog model.

Materials and Methods

Ethical approval

The research proposal was approved by the Ethical Committee of Faculty of Dentistry, Ain Shams University, Egypt (number: 790-Endo). Furthermore, the authors adhered to all the recommendations outlined in the Animal Research: Reporting in Vivo Experiments (ARRIVE) guidelines.

Animal model
The sample size was determined based on earlier studies (1, 15) using the G*power software 3.1.9.2, where a large effect size of 1.38 was detected. The significance level (α-error) was set at 0.05 and the power (1-β error) was set at 0.8 using two-sided hypothesis test. The estimated sample size was 8 for each subgroup at each evaluation period. The research involved six adult mongrel dogs weighing 17-20 kg. The age of dogs ranged between one and two years and they were of both sexes. Standardized periapical radiographs were taken to confirm complete root formation and absence of dental pathologies. The study was conducted at the Faculty of Veterinary Medicine, Cairo University, Egypt where the dogs were kept individually in separate kennel and received proper nutrition, ventilation and humidity.

Animal model classification
Twelve premolar teeth were used in each selected dog. A total of 72 teeth were divided according to post-treatment evaluation period into two main equal groups (three dogs' each/36 teeth each) including; group I: evaluated after one month and group II: evaluated after three months. Each main group was subdivided into three experimental subgroups (8 teeth each) according to the perforation repair materials used, and two control groups. The perforations in subgroups 1, 2 and 3 were sealed with NeoMTA™ Plus® (Avalon Biomed Inc. Bradenton, FL, USA), Nano-White MTA (Tooth-colored MTA, DENTSPLY, Tulsa Dental, Tulsa, OK, USA) and MTA Angelus® (Londrina, Brazil), respectively. The details of materials used in this study are shown in Table 1.
In the positive control subgroup (8 teeth), the perforations were done with no repair. Negative control subgroup (4 teeth) represented intact teeth with no perforation to show the normal histology (18, 19).

Anesthetic procedure
Each dog was anesthetized with general anesthesia after fasting for 12 hours. The dogs were pre-medicated with 0.05 mg/kg body weight Atropine sulphate (Atropine 1%®, ADWIA, Egypt) injected subcutaneously and 1 mg/kg body weight Xylazine HCl (Xylaject HCl 2%®, ADWIA, Egypt) injected intramuscularly. General anesthesia was induced by using Ketamine HCl (Ketamine 5%®, EPICO, Egypt) injected intravenously using a cannula fixed in the cephalic vein at a dose of 5mg/kg body weight. The anesthesia was maintained by using Thiopental sodium (Thiopental Sodium®, EPICO, Egypt) at a dose of 25 mg/kg body weight 2.5% injected intravenously (dose to effect).

Teeth instrumentation
Prophylaxis disinfection of the operative field was done using 2% chlorhexidine gluconate solution (JK Dental Vision CO., India). After general anesthesia, access cavity was done in all experimental and positive control teeth. Exposure of the pulp chamber was obtained through the occlusal surface using No.4 round bur with high-speed hand piece mounted on a portable air motor (X-Smart; Dentsply Tulsa Dental Specialties). Pulp extirpation was performed using large spoon sterile excavator. Working length was determined with an electronic apex locator (NSK Inc., Kanuma, Japan). Root canals were instrumented with ProTaper Next (Dentsply Maillefer, Ballaigues, Switzerland) to size X4 (40/06) mounted on handpiece of an electric motor under irrigation with 3.6 mL 1% sodium hypochlorite (NaOCl). After drying the canals with paper points (Meta Biomed CO., LTD, Korea), root canals were obturated by lateral condensation of gutta-percha cones (META, China) and AD Seal sealer (Meta Biomed CO., LTD, Korea).

Perforation creation
Perforation was induced in the central region of the pulpal chamber floor with #4 round diamond bur (KG Sorensen, Sao Paulo, SP, Brazil). The diameter of the perforations was standardized as being the diameter of the bur used. A 1.4 mm-diameter furcation perforation was done at low speed hand piece in both experimental and positive control subgroups until the hemorrhage was observed. The perforation depth was limited to 2 mm into the alveolar

Table 1

Materials used for perforation repair in this study

Brand name	Lot number	Expiration date	Composition	Setting time (Minutes)	Manufacturer
NeoMTA Plus®	2023-NMTA-1	31/8/2024	Tricalcium silicate, Dicalcium silicate, Tantalum pentoxide	20	Avalon Biomed Inc. Bradenton, FL, USA
Nano White MTA®	NWMTA- 789	30/9/2024	Tricalcium silicate, Bismuth oxide	30	Tooth-colored MTA, DENTSPLY, Tulsa Dental, Tulsa, OK, USA
MTA Angelus®	ANG-4567	15/7/2024	Tricalcium silicate, Zirconium dioxide	15	Londrina, Brazil

bone by a rubber stopper (1). A new bur was used for every 3 perforations. Hemostasis was achieved with abundant sterile saline (NaCl 0.9%) and gentle pressure with sterile cotton pellets (1, 18).

Perforation repair

The perforations were immediately sealed according to the subgroups. In subgroups 1, 2 and 3, the materials were mixed according to the manufacturer's instructions, carried into the perforation sites by small MTA carrier and compacted with a suitable sized plugger. A sterile wet cotton pellet was then placed in the access cavity. Radiographs were taken to confirm the perforation repair with the intended cements. Positive control subgroup was cleaned by saline (NaCl 0.9%) and no repair material was used and the defect was sealed by Teflon (Chemours Company, USA) (15). No perforations were performed in the negative subgroup.

All experimental and control subgroups were represented in each dog. The coronal access cavities of all experimental and positive control teeth were sealed with chemical cured glass ionomer filling material (Medifil, Promedica, Germany).

All dogs were given intra-muscular injections of Cefotaxime sodium at a dose of 10 mg/kg (Cefotax 250 mg vial®, T3A Co., Egypt) and Diclofenac sodium at a dose of 1.1 mg/ kg (Voltaren 75 amp®, Novartis Co., Egypt) once daily for five postoperative days (20). The dogs were kept under continuous monitoring for any changes in habits, body weight and food intake during the post treatment evaluation periods. Then, all animals were sacrificed according to the designated observation period by an overdose of Thiopental sodium.

Histological evaluation

The maxillae and mandibles were surgically dissected and cut into four quadrants to accelerate the decalcification time. Specimens were fixed in 10% neutral buffer formalin for 14 days then EDTA solution 17% MD- (ChelCream, Meta Biomed, Korea) for 120 days. During that period the decalcifying solution was changed by a fresh mix every 2 days. Decalcification was confirmed clinically by confirming that a surgical lancet can pass without resistance through cortical bone. Each block was trimmed 1 mm away from the edge of perforation in mesiodistal direction in each sample. The specimens were washed in running water for 24 hours. A code number was given for each specimen. The specimens were processed by using an open processing system in which the specimens were dehydrated in ascending grades of ethyl alcohol 70%, 95%, and absolute alcohol in 18 hours, cleared in xylene and embedded in paraffin wax. Thin sections (4-6µ) of each block were cut using a microtome through the area of

the furcal perforation. Slides were stained with hematoxylin and eosin stain. Under the light microscope (BX60, Olympus, Japan), the sections were examined and the inflammatory cell count was evaluated. It was assessed according to Salman et al. (21). For each slide, 3 representative fields were analyzed. Fields were characterized by well- preserved tissue with good architecture and intense inflammatory cell infiltration and without artifacts. Total inflammatory cell number was counted using image analysis software (Image-J software, 1.41a, NIH, USA). The color-coding threshold was adjusted to select the perimeter of the whole range of inflammatory cells to exclude other non-desired structures. Then, binary thresholds of the selected color-coded inflammatory cells were completed prior to calculation. The total number of cells was then counted as a factor of 10^3.

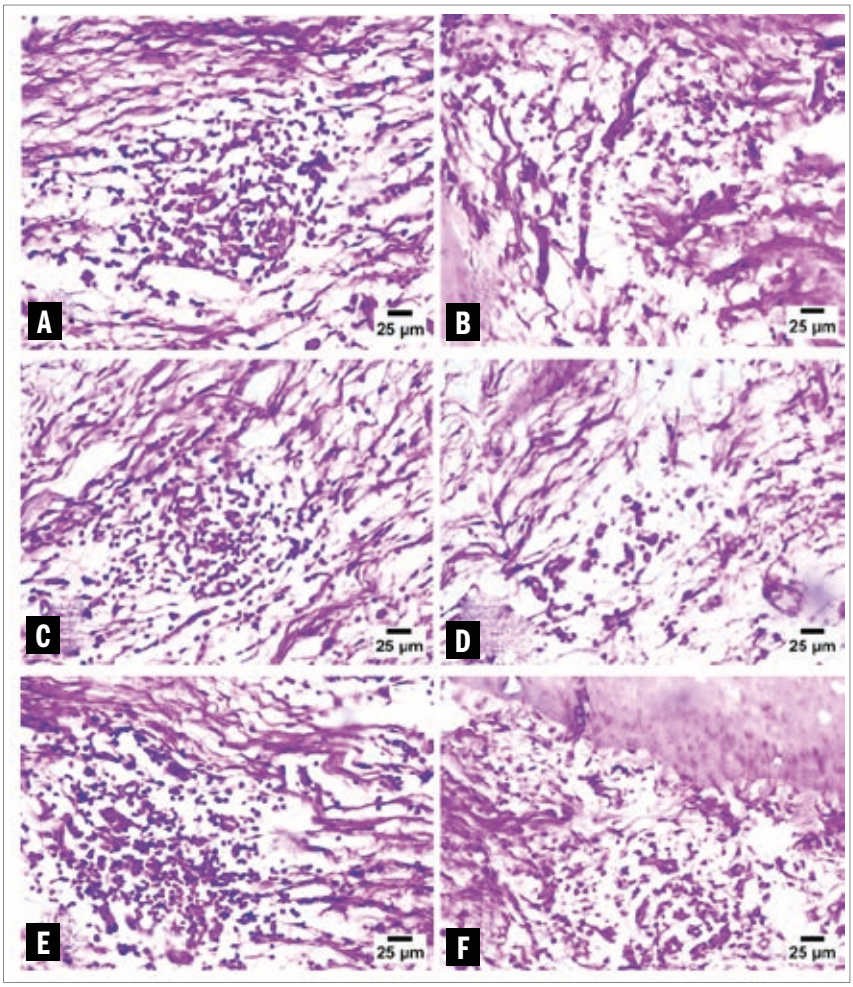

Figure 1
Photomicrographs showing inflammatory cell count for Neo MTA plus **(A),** Nano-WMTA **(C)** and MTA Angelus **(E)** at one month evaluation period. Photomicrographs showing inflammatory cell count for NeoMTA plus **(B),** Nano-WMTA **(D)** and MTA Angelus **(F)** at three months evaluation period (magnification, x400).

Immunohistochemical evaluation
Immunohistochemical staining was performed using Osteonectin antibody to identify new hard tissue formation. Paraffin sections were mounted on positively charged slides by using avidin-biotin-peroxidase complex (ABC) method. Sections from each subgroup were incubated with primary antibodies and then the reagents required for ABC method were added (Vectastain® ABC-HRP kit, Vector laboratories, USA). Marker expression was labeled with peroxidase and colored with diaminobenzidine (DAB, Sigma, Japan) to detect antigen-antibody complex. Negative control samples were included using non-immune serum in place of the primary or secondary antibodies. The stained sections were examined via using Olympus microscope (BX-53). The sections were graded according to Al-Hadainy et al. (22) scoring system as follows: Score 0: no bone formation, Score 1: slight bone formation, Score 2: moderate bone formation and Score 3: heavy bone formation.

Statistical analysis
All data were expressed as mean and standard deviation values. Data were explored for normality using Kolmogorov-Smirnov and Shapiro-Wilk tests. One-way ANOVA followed by tukey post hoc test was used to compare between more than two non-related samples. Repeated measure ANOVA followed by Paired sample t-test was used to compare between more than two related samples. Independent sample t-test was used to compare between two non-related samples. The significance level was set at $P \leq 0.05$. Statistical analysis was performed with IBM® SPSS® Statistics Version 20 for Windows.

Results

Histological findings
In both groups, positive control subgroup showed the highest mean value of inflammatory cell count while the least mean value of inflammatory cell count was found in negative control subgroup. Representative photomicrographs of all experimental subgroups in both groups are shown in Figure 1.

Table 2

The mean, standard deviation (SD) values of inflammatory cell count in all groups and subgroups

Subgroups	Group I (After one month)		Group II (After three months)		p-value
	Mean	SD	Mean	SD	
Subgroup 1 (NeoMTA Plus)	558.63^{bA}	46.51	445.13^{bB}	17.14	<0.001*
Subgroup 2 (Nano-WMTA)	539.63^{bA}	33.76	406.63^{bB}	53.71	0.001*
Subgroup 3 (MTA Angelus)	565.50^{bA}	29.20	455.00^{bB}	56.13	<0.001*
Positive control subgroup	866.63^{aA}	35.04	862.63^{aA}	43.91	0.851ns
Negative control subgroup	69.00^{cA}	6.19	68.00^{cA}	6.00	0.755ns
p-value	<0.001*		<0.001*		

*Mean with different small letters in the same column indicate statistically significance difference and mean with different capital letters in the same row indicate statistically significance difference. *Significant at p<0.05. ns: non-significant at p>0.05.*

Regarding effect of time periods on inflammatory cell count (Figure 2), there were statistically significant differences between group I (After one month) and group II (After 3 months) in all experimental subgroups (p≤0.001). Group I had significantly higher inflammatory cell count than group II. Regarding the effect of experimental materials on inflammatory cell count: there was no statistically significant difference between NeoMTA™ Plus®, Nano-WMTA and MTA Angelus® in both groups I and II (p<0.05). In both groups, the highest mean value was found in MTA Angelus® while the least mean value was found in Nano-WMTA (Table 2).

Immunohistochemical findings

In groups I and II, there were statistically significant differences between positive control subgroup and each of experimental subgroups (p≤0.001). Also, a statistical-

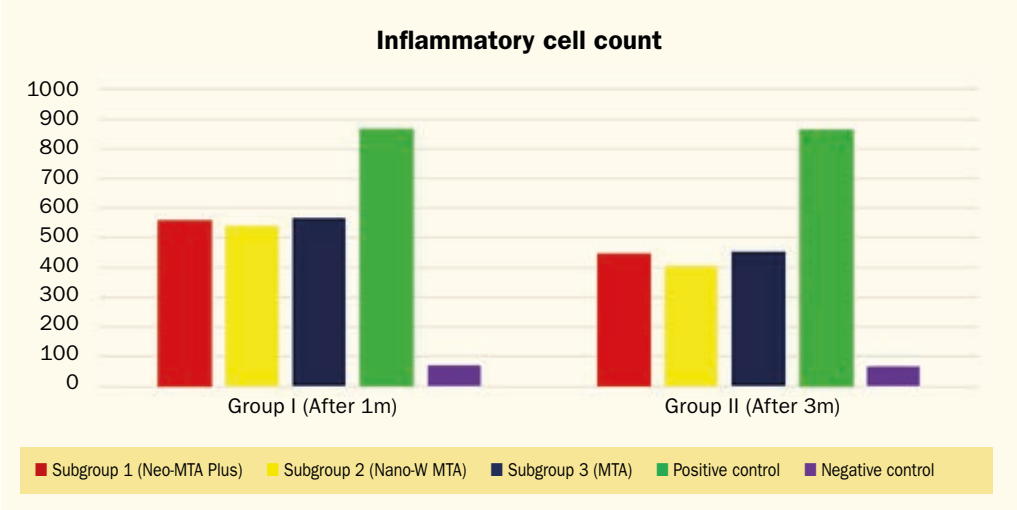

Figure 2
Bar charts representing effect of time periods on inflammatory cell count in different groups.

Table 3

The mean, standard deviation (SD) values of bone formation at all groups and subgroups

Subgroups	Group I (After one month)		Group II (After three months)		p-value
	Mean	SD	Mean	SD	
Subgroup 1 (Neo-MTA Plus)	1.50^{aB}	0.53	2.63^{aA}	0.52	0.024*
Subgroup 2 (Nano-WMTA)	1.63^{aB}	0.52	2.7 ^{aA}	0.46	0.020*
Subgroup 3 (MTA Angelus)	1.38^{aB}	0.52	2.25^{aA}	0.46	0.038*
Positive control subgroup	0.00^{bA}	0.00	0.00^{bA}	0.00	1ns
Negative control subgroup	0.00^{bA}	0.00	0.00^{bA}	0.00	1ns
p-value	<0.001*		<0.001*		

*Mean with different small letters in the same column indicate statistically significance difference and mean with different capital letters in the same row indicate statistically significance difference. *Significant at p<0.05. ns: non-significant at p>0.05.*

ly significant difference was found between negative control subgroup and each of experimental subgroups (p≤0.001) as shown in Table 3. Both positive and negative control subgroups showed 0 score in hard tissue formation. Representative photomicrographs of all experimental subgroups in group II are shown in Figure 3.

Effect of time periods on bone formation

Regarding the mean value of bone formation, there were statistically significant differences between group I and group II in all experimental subgroups (Table 3). Group II exhibited higher mean value of bone formation than group I in all experimental subgroups.

Effect of experimental materials on bone formation

There were no statistically significant differences in mean value of bone formation between NeoMTA™ Plus®, Nano-WMTA and MTA Angelus®. The highest mean value of bone formation was found in subgroup 2 (Nano-WMTA) while the least mean value was found in subgroup 3 (MTA Angelus®).

Discussion

Perforation repair materials should have high flowability to adapt to the complicated anatomy of root canal systems, strong biocompatibility to minimize unfavorable re-

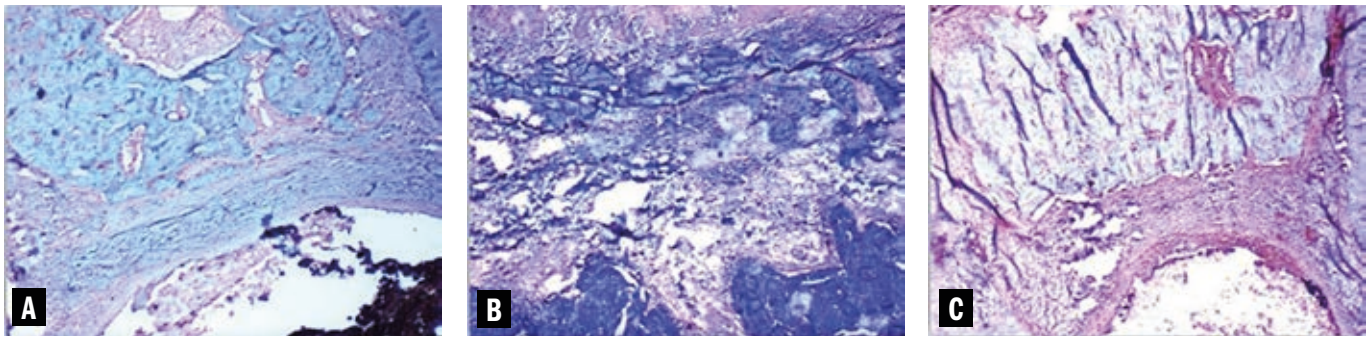

Figure 3
Photomicrographs showing positive response to Osteonictin antibody at furcation area **(A)** NeoMTA plus, **(B)** Nano-WMTA and **(C)** MTA Angelus.

actions with surrounding tissues, and radiopacity to permit monitoring during post-treatment assessments (1-3).The location and size of the perforation, the clinician's experience and preference, and the patient's overall oral health all influence the choice of perforation repair material (23).

MTA is commonly considered as the gold standard perforation repair material in dentistry (1-3). This is because of its extraordinary qualities, such as high biocompatibility and sealing ability (24, 25). Nevertheless, there are some drawbacks of MTA such as long setting time, technique sensitive and washout during initial setting (26, 27).

In endodontics, premixed bioceramic sealers and standard MTA powder-liquid formulations have significant advantages. Bioceramic sealers are pre-mixed for uniformity, have high biocompatibility and antibacterial qualities, and may aid in tissue healing. MTA has a solid track record for numerous endodontic operations, as well as long-term stability. MTA is adaptable and well-established, whereas bioceramic sealers are consistent and eliminate mixing errors (28-30). Their selection is determined by clinical preferences, case requirements, and physician experience. To increase the consistency of MTA powder-liquid formulations, putty formulations have been produced.

One of the improved versions of traditional MTA is NeoMTA™ Plus®. In comparison to MTA, NeoMTA™ Plus® has various components that provide several benefits in endodontics (31, 32).

The inclusion of radiopacifiers in endodontic root restoration materials is required for these materials to be visible on radiographs. However, the radiopacifier used can have a considerable impact on the biological features of these materials, such as cell inflammation and biocompatibility. Common radiopacifiers include bismuth oxide, zirconium dioxide, and tantalum pentoxide, which have diverse effects on materials and biological responses (33). Bismuth oxide (found in ProRoot MTA) has been linked to increased inflammation in certain studies, but zirconium dioxide (found in MTA Angelus®) and tantalum pentoxide (found in NeoMTA™ Plus®) are commonly thought to be superior solutions for limiting tissue irritation (33). Individual patient characteristics, material composition, and clinical approach can all have an impact on the overall biocompatibility of endodontic materials.

Nano-WMTA is a cutting-edge dental material that is a new advancement of classic MTA used in endodontics and restorative dentistry. Nano-WMTA has superior handling features, smoother consistency, and shorter setting times when compared to MTA, shortening treatment duration and potentially saving important chair time for both patients and dentists (34, 35).

The objective of this study was to assess the effectiveness of Nano-WMTA versus NeoMTA™ Plus® and MTA Angelus® when used for immediate furcation perforation repair. The current findings demonstrated that Nano-WMTA exhibited lower inflammatory cell count and higher new bone formation than both NeoMTA™ Plus® and MTA Angelus® in both groups with none statistical significant differences.

This study used an animal model to establish and control surgical circumstances that would be impossible to perform in a clinical situation, allowing for the creation of perforations and the gathering of histologic data that would be difficult to get in human beings. Because of their well-developed root structures and the accessibility and visibility afforded by their furcation area, dogs were chosen as the animal model (1-3). Furthermore, due to their faster growing rate, dogs have comparable apical healing mechanics with humans in a shorter duration (average 1/6 of human). They have the same mineral structure and organic responses as humans and can survive long periods of research under general anesthesia (18). The furcation in dog premolars is 1 to 2 mm from the cement enamel junction, but the furcation in human teeth is deeper within the alveolus (15, 20, 36). As a result, any technique or cement that has been proved to create beneficial effects in dogs may produce a more favorable reaction in humans, since the distance between the CEJ and the furcation area is greater (18, 37). According to

earlier research, the standardized perforation size was fixed at 1.4 mm, and the bur penetration depth was limited to 2 mm in order to trigger the inflammatory response (1, 38).

The current study used immediate seal of perforation because it is critical in preventing potentially serious consequences and guaranteeing satisfactory treatment outcomes. Dental practitioners can avoid bacterial entry into the root canal system and surrounding tissues by sealing the perforation as soon as possible, lowering the risk of infection, inflammation, and potential tooth loss. Furthermore, the initial seal contributes to the preservation of the natural barrier between the pulp space and the periapical tissues, promoting good healing responses and assisting in the retention of tooth vitality (39).

In the current study, two evaluation periods were chosen: one and three months. The inflammatory phase is usually over after one month. However, the second evaluation time of three months is required for the procedure's ultimate judgment. The majority of research that used animal models to evaluate histopathological tissue reactions for various endodontic procedures and/or materials used the same time frame (1, 15, 18).

Histological evaluation following perforation repair is critical for determining the healing response and biocompatibility of the repair materials utilized. It enables quantitative examination of characteristics such as mineralized tissue creation and the presence of inflammatory cells, providing objective data for assessing the success of perforation repair (18, 40).

Immunohistochemical analysis is a specialized and powerful approach that involves the use of specific antibodies that target certain proteins or cellular markers in repair tissue samples. Researchers and doctors can use immunohistochemistry to identify and quantify specific cell types, inflammatory indicators, growth factors, and tissue-regenerating chemicals found in healed tissues (41). Osteonectin is a glycoprotein that is found in the extracellular matrix of numerous tissues such as bone, cartilage, and connective tissues. It is essential for tissue remodeling, cell-matrix interactions, and cell behavior modulation. As a result, it is frequently employed to identify and investigate bone regrowth. When osteonectin antibody is given to tissue sections, it binds to osteonectin if it is present. A chromogenic or fluorescent marker is then used to visualize the attached antibody, allowing researchers to establish the location and distribution of osteonectin inside the tissue (42).

Regarding the histologic evaluation, inflammatory cell count in the three experimental materials at both time periods showed that, the highest amount of inflammatory cell count was at the positive control group due to presence of microorganisms in furcation site and its direct contact with the oral cavity (13). On the other hand, MTA Angelus®, NeoMTA™ Plus® and Nano-WMTA showed statistically significant lower amount of inflammatory cell count than the positive control due to good sealing ability, biocompatibility, alkaline pH on setting (15, 17), and the closure of the access cavity that prevents further infection at the furcation perforation (6). The three experimental groups had no statistically significant difference in the inflammatory cell count; this is probably due to the high similarity in the chemical composition between the materials.

Regarding the effect of time periods on inflammatory cell count, for all tested materials, a higher inflammatory reaction was found in the one-month period and decreased at three months. This might be attributed to the time factor that when increased, the inflammatory reaction decreased upon the application of the biocompatible materials. Similar findings were reported by earlier authors (1, 37, 43, 44).

Results of immunohistochemical analysis showed that, positive control subgroup recorded significantly lowest mean value with no scores for new hard tissue formation at both time periods. This was due to persistence of chronic inflammation throughout the periods of the study and continued release of inflammatory mediators which prevent regeneration ability of the tissues. Similar finding was recorded before (1).

There were no statistically significant differences in new hard tissue formation between the three experimental materials within both groups (13). Results showed that after three-month evaluation period, there were statistically significant high scores of hard tissue formation in all experimental subgroups. This could be explained by the sealing ability, biocompatibility and alkaline pH on setting that accelerates new hard tissue formation (45). Calcium ions produced by the three materials may be the source of calcification, since they can react with phosphate ions in tissue fluids, resulting in the production of an amorphous calcium-phosphate layer, which is a precursor to calcification, and the formation of hard tissue barriers. The one-month evaluation period yielded the lowest grade for hard tissue development. This is due to the increased inflammatory response during this time period. This is consistent with past research (1-3, 46).

Conclusions

The Nano-White MTA, NeoMTA™ Plus® and MTA Angelus® were able to reduce inflammation and induce new hard tissue formation over time. Although Nano-WMTA exhibited lower inflammatory cell count and more new bone formation values than NeoMTA™ Plus® and MTA Angelus®, there were no statistically significant differences between the tested materials in terms of inflammatory cell count and new bone formation.

Clinical Relevance

Nano-WMTA can alternate both NeoMTA™ Plus® and MTA Angelus® when used as a root repair material.

Conflict of Interest

There are no conflicts of interest.

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ORIGINAL ARTICLE

Physico-mechanical properties of two different heat treated Nickel-Titanium instruments: in-vitro study

ABSTRACT

Aim: *This study aimed to define physico-mechanical properties of recently introduced thermally treated Edge Taper Platinum (ET Platinum) Nickel-Titanium (NiTi) instruments compared to conventional NiTi Edge Taper (ET) to disclose improvements obtained by heat-treatments.*

Methods: *ET and ET Platinum instruments (n=30/each) were rotated until fracture in a stainless-steel canal with 90°curvature angle and 5mm curvature radius. Time to fracture (TtF) and number of cycles to fracture (NCF) were calculated and results were analyzed using Mann-Whitney test (p=0.05). Fractured instruments underwent fractographic analysis under Field-Emission-Gun Scanning Electron Microscope (FEG-SEM). Superficial features of additional new ET and ET Platinum instruments were analyzed under SEM at increasing magnification with standardized angulations and positions. After inspection, ET and ET Platinum instruments were used in extracted teeth to shape 4 straight canals each to simulate clinical conditions and re-evaluated under SEM at the same points to detect superficial wear features. ET and ET Platinum brand new instruments were examined by differential scanning calorimetry (DSC) to assess transformation temperatures.*

Results: *Cyclic fatigue test showed a significant increase of fatigue resistance on ET Platinum compared to ET instruments (p=0.05). Fractographic analysis demonstrated a pattern of fatigue propagation on both instruments. SEM analysis on brand new instruments revealed a more regular surface of ET Platinum compared with ET and both instruments appeared with minimal alterations after the simulated clinical use. DSC analysis demonstrated higher amounts of martensite at 37°C in ET Platinum compared to ET instruments.*

Conclusions: *ET Platinum instruments displayed an improved mechanical behavior, possibly related to modified phase transformation temperatures induced by thermal treatment of the alloy during manufacturing process. These results suggest a safe use in clinical conditions.*

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Introduction

In the last decade many new designs, alloys, manufacturing processes, heat treatments and kinematics of Nickel-Titanium (NiTi) instruments have been introduced by several manufacturers (1). Recent strategies are focused to improve the mechanical properties of NiTi instruments through different thermomechanical treatments with the aim to optimize the alloy microstructure (2). In fact, heat-treatments are known to modify the intrinsic features of NiTi alloy due to the shift in crystalline structure (3, 4). The martensite/austenite transformation temperatures have been adjusted to allow a higher percentage of martensitic phase either at room, or body temperature, leading to more flexibile NiTi instruments and with an increased cyclic fatigue resistance compared to austenitic instruments; this is known to reduce intra-canal separation during clinical use (5).

Recently EdgeEndo (Albuquerque, NM, USA) has commercialized the heat-treated EdgeTaper Platinum (ET Platinum) rotary instruments. According to the manufacturer, ET Platinum instruments have the same design and geometric characteristic of EdgeTaper (ET), differing exclusively for the NiTi heat-treatment technology (EdgeTaper Platinum Brochure, EdgeEndo, Albuquerque, NM, USA).

ET are characterized by a bilobated triangular cross section with a progressive changing taper which tended to decrease at the middle and coronal portions. The operative system is based on an SX orifice opener (#19/12) an S1 (#17/09) and S2 (#20/06) series for shaping the canal and an F1 (#20/05), F2 (#25/05), F3 (#30/04), F4 (#40/05) and F5 (#50/05) series to finish the root canal instrumentation. The alloy of ET Platinum (Fire-Wire™) has been developed to improve flexibility and to enhance resistance (6). Fire-Wire™ is claimed to consist of an annealed heat-treated, cryogenically tempered NiTi alloy (7, 8) that should be in martensitic phase at body temperature.

The aim of the present study was to analyse the mechanical properties of recently introduced ET Platinum in comparison with not heat-treated ET instruments to better understand the improvements associated to the heat-treatment and if these instruments are suitable for the clinical use.

Materials and Methods

Cyclic Fatigue Resistance and Fractographic analysis

New ET (n=30, batch 070906170) and ET Platinum (n=30, batch 070918172) F1 size #20 with .06 variable taper and 25 mm length were rotated in a stainless steel (AISI 300) block containing a simulated canal with an angle of curvature of 90°, a radius of 5 mm and the centre of the curvature at 7 mm from the tip of the file (3) following manufacturer's recommendations (300 rpm) until fracture occurred. A fixed tool guaranteed a standardized placement of the instruments inside the artificial canal. Time to fracture (TtF) was recorded with a digital stopwatch and the numbers of cycles to fracture (NCF) was calculated using the following formula: $NCF=TtF(s) \times rotation\ speed(rpm) \times 60s^{-1}$. Fragment length (FL) was measured using a digital caliper.

Fractured samples were cleaned to obtain a clear surface, in an ultrasonic bath containing a solution of isopropyl alcohol for 5 minutes at room temperature immediately before placing in the FEG-SEM. Instruments separated during cyclic fatigue test were subjected to fractographic analysis using a FEG-SEM (FEG-SEM - Nova NanoSEM 450, FEI, Eindhoven, Netherlands) and micrographs from 500x to 5000x were taken on the fractured surface.

SEM analysis and Wear test

Human extracted teeth were used to perform wear test. Theeth were removed due to orthodontic or periodontal reasons and were caries free without any root canal treatment. Patients were informed and agreed with the use for scientific research purpose. The approval of the Ethical Committee was obtained (Prot. n. 000083).

A Scanning Electron Microscope (SEM) (JSM-5200, JEOL, Tokyo, Japan) was used to evaluate superficial features of brand

new additional instruments ET (n=3) and ET Platinum (n=3). Micrographs were taken at increasing magnification from 50× to 5000×, with standardized angulations and positions, at the tip of the instrument and on cutting edges at 5 mm from the tip. After the SEM examination these instruments were subjected to wear tests to simulate clinical conditions, using straight and round canals selected from a pool of extracted human teeth (9) evaluated radiographically with a mesio-distal and bucco-lingual angulation (4). Canal width of one-rooted teeth (n=24) was evaluated and measured on radiographs at 5 mm from the apex using a periodontal probe. Only teeth with canal width between 1 mm and 1,5 mm, at 5 mm far from the apex were accepted. Each tooth was sectioned at the cementum-enamel junction with a water-cooled diamond wheel saw in order to obtain a standard root length of 15 mm. Canal patency was verified with #10-15 stainless steel manual K-file and the working length was visually determined by insertion of a 25-mm #10 K file until its tip appeared at the apical foramen. Pre-flaring was achieved with an ET SX instrument 19/.12 19mm length (EdgeEndo, Albuquerque, New Mexico) and canal shaping was obtained with ET (n=3) and ET platinum (n=3) instruments 25 mm length S1 17/.06v and S2 20/.07v (EdgeEndo, Albuquerque, New Mexico). Instruments were used with a 16:1 reduction endodontic handpiece X-Smart Plus (Dentsply Maillefer, Baillagues, Switzerland) following manufacturer's recommendations at 300 rpm and 2.5 N·cm, with pecking motion. Irrigation was performed with 3 ml of 5% NaOCl (Niclor 5, Ogna, Muggiò, Italy) and 3 ml of 10% EDTA (Tubuliclean, Ogna, Muggiò, Italy). Every step was performed by the same expert operator. Each instrument was used in 4 canals, washed in an ultrasonic bath containing enzymatic solution for 10 min and then autoclaved at 134.8 °C (10). These multi-used instruments were observed at SEM after this wear test at the same points and angulations to identify the wear features. Wear was evaluated comparing the pre- and post-operative micrographs, to verify the presence of unwinding, microcracks, blade disruption and tip deformation (10-13).

Differential Scanning Calorimetry

Brand new ET (n=1) and ET Platinum (n=1) instruments were subjected to Differential Scanning Calorimetry (DSC, DSC2010, TA Instruments, New Castle, US-DE). Instruments were sectioned in their working portion in order to obtain a weight of 15mg and placed in an aluminum crucible to perform multiple heating and cooling cycles from -40 °C to 110 °C with a heating/cooling rate of 5 °C min^{-1}. Data were analyzed using software Universal Analysis 2000 (TA Instruments).

Statistical analysis

Data regarding the Cyclic Fatigue Resistance were analysed through Sigmaplot software (Systat, USA). Due to the non-normal distribution of the data (normality test>.05), Mann-Whitney test was performed (p=0.05) as statistical analysis.

Table 1

Descriptive analysis for NCF, time to fracture (TtF) expressed in seconds (s) and fragment length (FL) expressed in mm for EdgeTaper and EdgeTaper Platinum. Mean and standard deviations (SD) are represented.

	NCF, mean ± SD	TtF (s), mean ± SD	FL (mm), mean ± SD
EdgeTaper	139.52±41.11	27.9±3.9	7.71±1.33
EdgeTaper Platinum	319.89±187.36	63.98±12.9	8.39±1.88
P value	<0.05*	<0.05*	>0.05

Results

Cyclic Fatigue Resistance and Fractographic analysis

ET Platinum instruments exhibited significantly higher mean TtF and NCF compared to ET instruments (p<.05). The

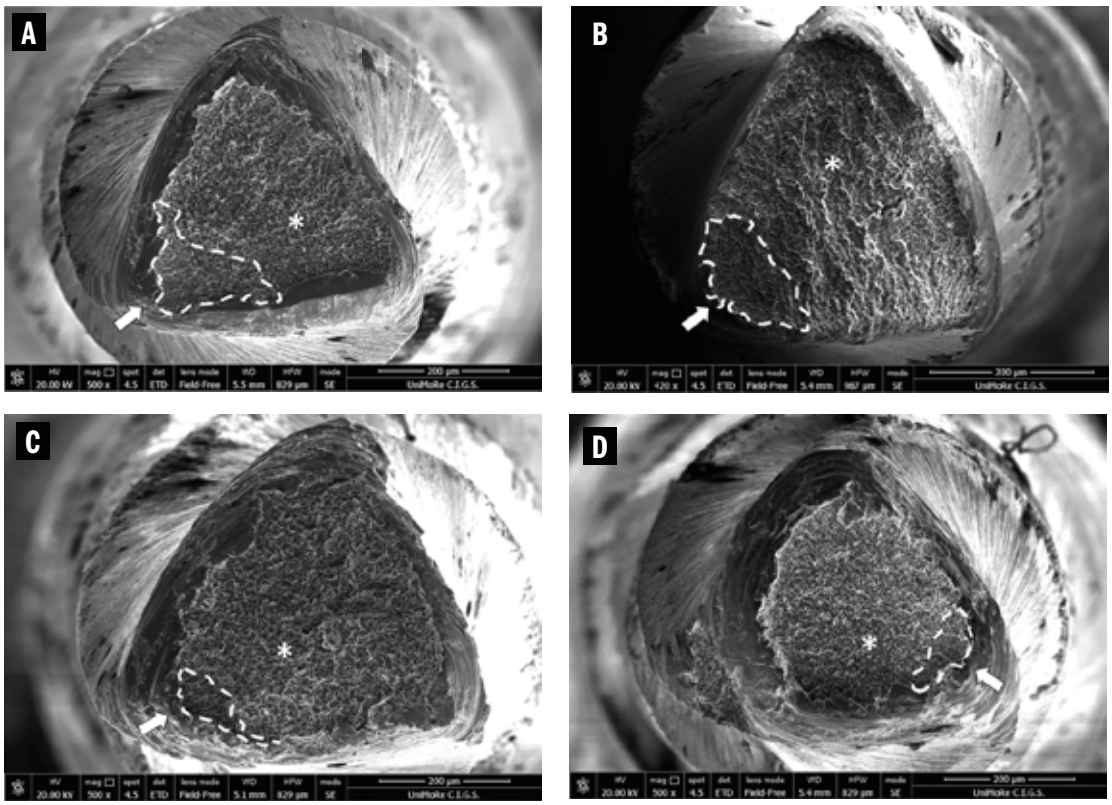

Figure 1
Fractographic analysis on ET **(A, B)** and on ET Platinum **(C, D)** instruments. In each micrograph the crack origin is identified and represented (white arrow), fatigue striation area (marked by white dotted line), and ductile fracture area (white asterisk) are noticeable.

difference in FL was not statistically significant (p>.05). Results are presented in Table 1.
On both groups of instruments, fractographic analysis revealed a small zone with fatigue striations next to a single crack origin in correspondence of an outer cutting edge, demonstrating a slow fatigue fracture propagation in this area. The remaining wider surface was covered by dimples, revealing the ductile fracture that caused the final rupture of the sample (Fig. 1). No pattern of torsional fracture was recognized in both instruments.

SEM analysis and Wear test
SEM analysis on brand new instruments revealed the presence of irregular grooves on the surface of ET, while ET Platinum exhibited a smooth regular surface (Fig. 2). Both instruments inspected as received from the manufacturer did not show fracture, microcracks, unwindings and the cutting edges were intact. Manufacturing residues were noticed on the surface of brand new ET instruments, but not on those of ET Platinum. After wear test, both types of instruments did not reveal surface degradation in terms of fracture, microcrack, unwinding, tip deformation and blade disruption. Both the groups of instruments showed the presence of residual dentinal debris on the cutting edges, which remained attached to the surface despite the ultrasonic bath and autoclaving cycle.

Differential Scanning Calorimetry
ET instruments exhibited a DSC peak that extends over a temperature range from +21.4 °C (Ms – martensitic start) to -14.9 °C (Mf – martensitic finish) during cooling (forward transformation) and a range from -7.6 °C (As – austenitic start) to +22.3 °C (Af – austenitic finish) during heating (reverse transformation) (Fig. 3). ET Platinum instruments showed a different behavior, with a DSC peak that extends over a temperature range from +33.5 °C (Ms – martensitic start) to +20.4

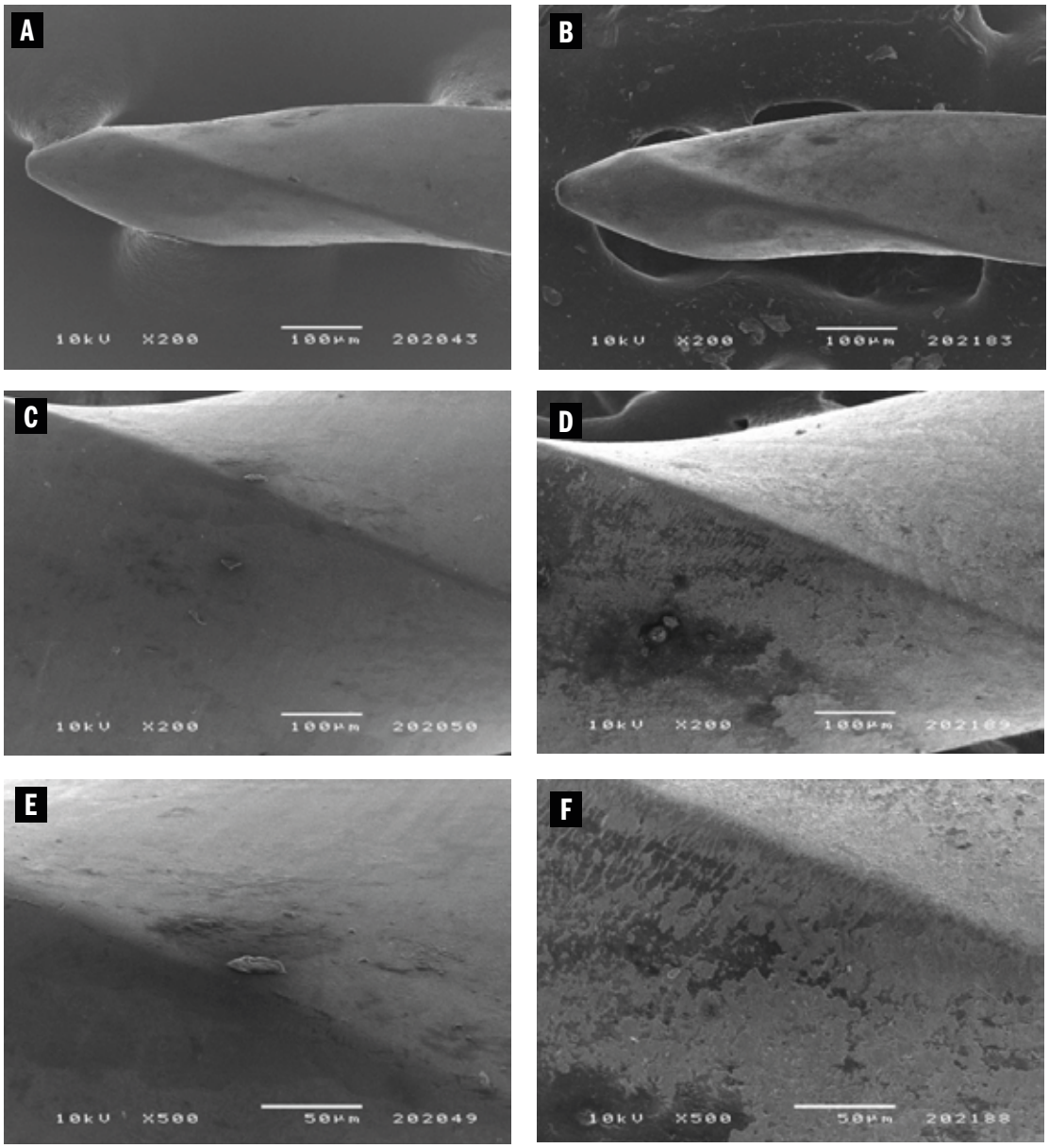

Figure 2
SEM analysis on ET Platinum before **(A, C, E)** and after **(B, D, F)** wear test. The outer surface exhibited a smooth regular texture. After wear test, no signs of surface degradation in terms of fracture, microcrack, unwinding, tip deformation and blade disruption were noticed. Residual dentinal debris on cutting edges after wear test, remained attached to the surface.

°C (Mf – martensitic finish) during cooling (forward transformation) and a range from +27.6 °C (As – austenitic start) to +44.5 °C (Af – austenitic finish) during heating (reverse transformation).

Discussion

This study pointed out that ET and ET Platinum rotary endodontic instruments share the same design, differing exclusively for the NiTi annealing heat-treatment. Considering this, every difference in their features may be attributed to this post-manufacturing process enabling comparability between the two groups. Therefore, these results could be translated also in other NiTi files which received the same heat treatment.
Results demonstrated that the heat-treatment greatly enhances the cyclic fatigue resistance because of the statistically significant increase in NCF of ET Platinum (heat-treated) compared to traditional ET (not heat-treated) instruments. In the present study the Fire-Wire™ alloy was found

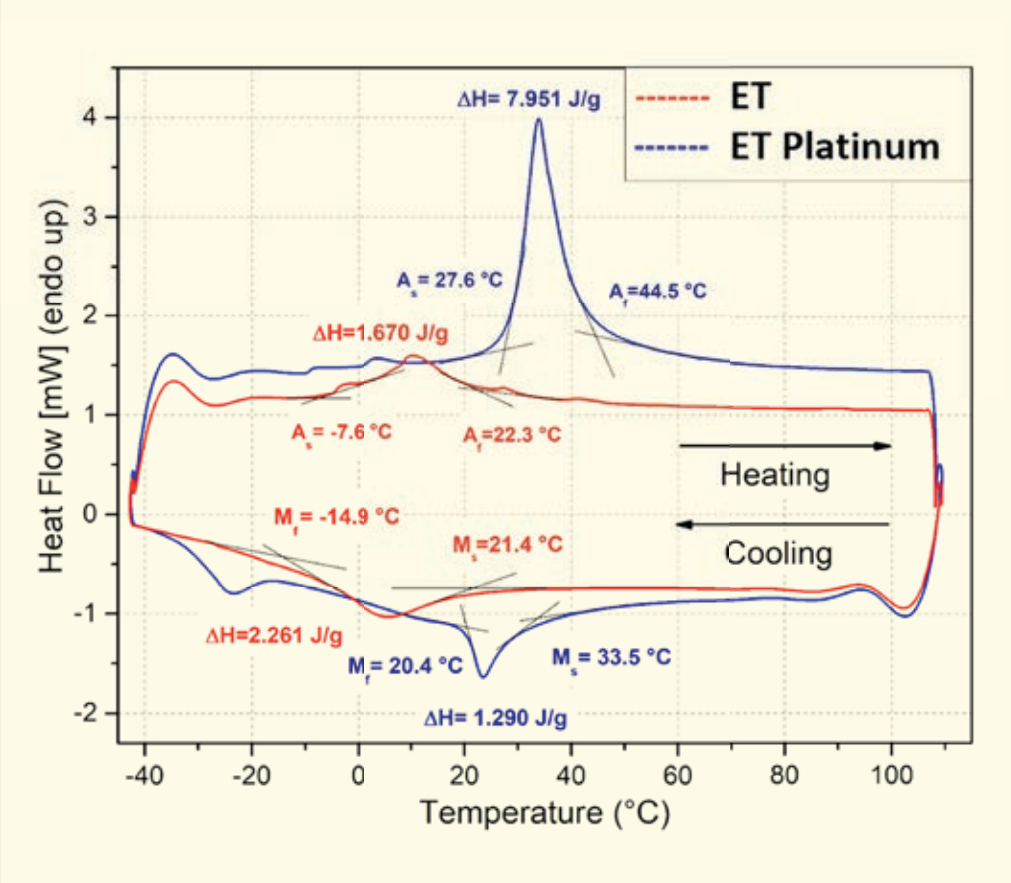

Figure 3
Differential scanning calorimetry (DSC) graphic representing phase transformation temperatures (°C) of ET (red line) and ET Platinum (blue line). The "endo up" plotting convention was followed; whereby endothermic peaks are in the positive direction of the y-axis and vice versa. The temperatures associated with the onset and completion of the austenite → martensite transformation (direct transformation) during cooling, labelled as M_s and M_f, and of the the martensite → austenite transformation during heating (reverse transformation), respectively labelled A_s and A_f, are indicated on the plot. Transformation enthalpies (ΔH) associated with each peak were calculated as the ratio of the overall amount of heat absorbed/released (respectively) by the sample during the transformation and the sample mass, and are specified on the plot next to the corresponding peaks, in units of J/g.

to be more resistant to cyclic fatigue when compared with the conventional NiTi alloy. As a matter of fact, the NCF of ET Platinum was almost 2.3 times higher compared to the austenitic ET, suggesting a safer clinical use especially in curved canals. The literature provides a comparison between the cyclic fatigue resistance of ET Platinum and another instrument of similar characteristics: the former still appears to be superior tested in a 60° 5 mm radius curved artificial canal (6). Similarly, in previous studies (8) Fire-Wire™ alloy instruments outlasted instruments made by M-Wire and Gold wire alloys both in continuous rotation and reciprocation. Scott et al. (2019) also reported a slightly different design of the tested instruments as a reason for the difference in cyclic fatigue resistance in their study (8). A comparison between ET Platinum and ProTaper Gold (14) reported a statistically significant higher cyclic fatigue resistance of ET Platinum, despite a lesser resistance to torsional load, thus confirming the results of Alcalde et al. (15). As mentioned, in the present study the tested instruments differed only for the heat treatment of the alloy and this eliminates the variables that can be connected with a different morphology of the compared instruments, such as section area, section design and taper. The homogeneity of the instrument's morphology between the two groups, and the rigorous set-up of the experimental conditions can explain why there was not statistically significant difference in the FL between the two groups.

FEG-SEM analysis of fractured instruments showed the typical pattern of cyclic fatigue fracture (16, 17), validating the chosen cyclic fatigue test procedure and confirming that no torsional load was simultaneously exerted on the instruments. In fact, SEM analysis of the fractured surface revealed a single crack ori-

gin on the cutting edge of both instruments, with a relatively small propagation area showing the typical fatigue striations, while the remaining part was covered by dimples and showed a ductile fracture pattern; Piao et al. (2014) conducted a similar and more extensive fractographic analysis procedure with different instruments (18). Heat-treated ET Platinum appears to have larger fatigue propagation area compared to ET, suggesting a longer crack propagation stage before the final fracture, compatible with the higher duration obtained through the cyclic fatigue test. Moreover, ET Platinum instruments presented more regular fractured margins, compared to the traditional ET. This could suggest that traditional ET had a sudden ductile fracture rather than a progressive propagation of the crack (17).

SEM analysis was selected for the assessment of the morphological characteristics of the instruments before and after wear testing, to verify the onset of superficial defects (3, 10, 11, 12, 19). Both ET and ET Platinum passed intact the wear test, which simulates clinical conditions, with no detectable alterations of their outer morphology. Both types of instruments did not reveal any surface degradation in the form of microcracks, tip deformation, fracture, unwinding, blade disruption during the test; so, it can be assumed that both instruments have high wear resistance under clinical conditions. Confirming this, Alfawaz et al. (2022) found ET Platinum to be less affected by working in a solution of NaOCl compared to other instruments (20). Interestingly, ET instruments revealed the presence of many irregular grooves on the surface before the test, unlike ET Platinum that exhibited a smoother and more regular surface. Nevertheless, the finding of an irregular surface on some new instruments, probably ascribed to some differences during the manufacturing process, did not affect the wear resistance (i.e. comparable results between groups). On the contrary, it can be speculated that the presence of an irregular surface can affect the cyclic fatigue resistance, contributing to the in significantly different results between ET and ET Platinum.

DSC assessment of martensitic conversion temperatures can help in predicting the behavior of NiTi rotaries in different environments (21-24). In the present evaluation DSC analysis revealed the phase transformation points of martensite and austenite in EdgeEndo Fire-Wire™ alloy. Because the reverse transformation peak of the ET Platinum file is centered approximately around the body temperature (37 °C), it is inferred that this file has a higher amount of martensite at the body temperature compared to ET, which is inferred to be completely austenitic, confirming the findings of a recent study (25). Thermo-mechanically treated NiTi alloys have been widely reported to possess an increased flexibility and an augmented cyclic fatigue resistance (5) and DSC data of the present study suggests that ET Platinum benefits from a higher amount of martensite, which is expected to make the material more flexible, hence more resistant to rotating bending fatigue. Considering the in-vitro design of the study, it can be completed with investigations to evaluate the impact of Fire-Wire™ alloy on the actual clinical effectiveness of the instruments.

Conclusions

Heat-treated NiTi ET Platinum instruments revealed an improved mechanical behavior compared to traditional NiTi ET, possibly related to a modified phase transformation temperature of the wire induced by thermal treatment during manufacturing process. Fire-Wire features analyzed in the present study suggest a safe use in clinical conditions.

Clinical Relevance

Clinically, the enhanced fatigue resistance and improved surface characteristics of ET Platinum instruments suggest a safer and more effective use in challenging endodontic procedures, espe-

cially in curved canals. The heat treatment process employed in ET Platinum instruments leads to a more regular surface and higher resistance to cyclic fatigue, which could significantly reduce the risk of instrument fracture during clinical procedures.

Conflicts of Interest

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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Institutional Review Board Statement
The study was conducted in accordance with the Declaration of Helsinki, and approved by the the Ethical Committee (Prot. n. 000083) "Comitato Etico di Area Vasta Emilia Centro della Regione Emilia-Romagna located in Azienda Ospedaliero - Universitaria di Bologna, Policlinico S.Orsola-MalpighiVia Albertoni, 15 - 40138 Bologna".

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ORIGINAL ARTICLE

Evaluation of two endodontic irrigation needles on curved root canal disinfection: an ex vivo study

ABSTRACT

Aim: *The study aimed to compare the effectiveness of two different irrigation needles in eliminating* E. faecalis *from contaminated curved root canals and to test their difference in flexibility.*

Materials and methods: *Thirty-five extracted multirooted teeth with visible curved canals were instrumented, autoclaved at 121 °C for 25 minutes, and contaminated with 10 µL of the bacterial suspension. The teeth were randomly divided into three groups: A (IrriFlex), B (Navitip), and C (Control). After an incubation period of 21 days at 37 °C, group C was irrigated with 20 µL of sterile saline solution. Groups A and B were irrigated with 5 ml of 5% sodium hypochlorite (NaOCl) solution by inserting the respective needle tip until the apical third, neutralized with 5 mL of 5% sodium thiosulfate and rinsed with 5 mL of sterile saline. Three sterile paper points for each sample were taken, transferred into a brain heart infusion (BHI) medium under aseptic conditions, and frosted immediately at -20 °C. Colony-forming unit (CFU) counting was assessed after microbiological culture on selective media for* E. faecalis. *A customized device was used to test the bending behavior of the tips at 3 mm, 6 mm, and 9 mm. Kruskal-Wallis and Dunn tests were used for statistical analysis.*

Results: *IrriFlex needle demonstrated higher flexibility with no statistical difference at 3 and 6 mm compared to NaviTip. NaOCl irrigation with NaviTip Tip and IrriFlex effectively reduced* E. faecalis *CFU count.*

Conclusions: *NaOCl irrigation with NaviTip Tip and IrriFlex demonstrated high and comparable efficacy in removing* E faecalis *from curved canals of multirooted teeth.*

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Introduction

Enterococcus faecalis is a Gram-positive coccus frequently isolated from secondary endodontic infections (1). *E. faecalis* can survive despite prolonged periods of nutrient deficiency (2), and it was demonstrated to be resistant to endodontic antimicrobials during endodontic treatment (3). This feature is related to *E. faecalis* proficiency to form dense biofilms and to invade dentinal tubules and root canal complexities (3), thus surviving the antibacterial action of sodium hypochlorite (NaOCl) (4). However, even though NaOCl can quickly oxide the membranes of those bacteria located more superficially within the biofilm, it is less effective on deeply embedded bacteria that remain protected from the direct action of chlorine (4). Microorganisms should be eliminated from the root canal system or reduced as much as possible to be compatible with healing to obtain a successful treatment outcome (5).

Although mechanical instrumentation may not completely eliminate microorganisms, particularly in cases featuring isthmuses, deltas, lateral canals, ramifications, and complex anatomies (4,6,7). Notably, complete microbial eradication from the apical third of the canal remains a considerable challenge, as 10-50% of the canal walls remain untouched by root canal instruments (8), regardless of the chosen instrumentation technique (9).

Microorganisms that persist despite chemo-mechanical preparation are widely recognized as the leading cause of failure after primary treatment and non-surgical retreatment (10). Therefore, effective endodontic irrigation is essential for root canal debridement, serving as the primary means to clean areas inaccessible to mechanical instrumentation (11). Achieving complete eradicate *E. faecalis* from the endodontic system requires the penetration of irrigating solutions deep into dentinal tubules (12).

In clinical practice, irrigation with a syringe and a needle remains the most used procedure to inject the solution deep into the root canal (13), although its efficacy in the apical region is uncertain (14). Available evidence suggests that the size, design, and insertion depth of the irrigation needle tip are essential in eliminating bacterial biofilms (15). Irrigation needles can be classified into two primary categories: *open-ended* needles that eject the irrigant directly through their tip and *closed-vented* needles with a closed tip expelling the irrigant through one or more side vents (10). Closed-vented needles must be positioned within 1 mm of working length (WL), while open-ended needles should be inserted 2-3 mm or less from WL (14). In recent years, alongside conventional stainless steel irrigation needles, other irrigation tips have emerged, aiming to enhance irrigation at the apical level, particularly in severely curved canals (16). Prominent examples include NaviTip (Ultradent, South Jordan, UT, USA) and IrriFlex (Produits Dentaires SA, Vevey, Switzerland). NaviTip is available in three different designs: NaviTip Tips, NaviTip Sideport Tips, and NaviTip FX Tips. NaviTip Tip is a stainless-steel open-ended cannula, slightly stiff at the base and centre but flexible at the end to facilitate penetration into curved canals. The tip is designed to reach deep into the canal to deliver the irrigant effectively. Tipically, irrigants advance about one mm past the delivery tip within the canal. Each NaviTip Tip has a smoothed-out, rounded end to navigate through curvatures without scratching or potentially causing ledges as it moves through the canal.

On the contrary, IrriFlex (27mm, 30G, 0.04 taper) is a unique irrigation needle composed of a double-side-vented soft polypropylene. It adapts smoothly to the anatomy of root canals, and has been proposed as an alternative to traditional metal needles. Furthermore, the flexibility of the polypropylene cannula allows for apical access without resistance or damage to the dentinal walls. It ensure reaching the predetermined WL, wihile avoiding the risk of extrusion in the periapical area. This feature enable balanced irrigant expulsion through two precise jets oriented directly against the dentinal walls (4,15).

The impact of irrigants on biofilm has received far less attention than other topics, such as debris and smear layer removal, which have been extensively investigated

(12). Moreover, the capability of IrriFlex and NaviTip Tip to reduce the mean *E. faecalis* colony-forming units (CFU) count in curved canals of multirooted teeth has not been quantified and compared yet in recent literature. Although IrriFlex is a widely used endodontic irrigation needle and is well known for its higher flexibility compared to conventional needles, no studies have quantified its actual bending ability. Furthermore, its flexibility has never been compared with that of NaviTip, which, as claimed by the manufacturer, is designed to ensure that the cannula's tip easily reaches the apical portion of any canal. Notably, adequate syringe irrigation depends on the proximity of the needles to the apical terminus of the root canal, especially in cases of severe curvature (12,16). The present study aimed to compare two irrigation needles' effectiveness in reducing E. faecalis CFU counts in in vitro contaminated root canals and assess their flexibility. Two null hypotheses were established: there was no statistically significant difference between the irrigation systems tested in eradicating *E. faecalis* from the root canal, and there was no statistically significant difference in flexibility between the two cannulas.

Methodology

Sample Collection and Preparation

This *ex vivo* study was approved by the ethical committee of Azienda-Ospedaliero Universitaria Senese number 7/2021. Thirty-five multirooted teeth extracted for either orthodontic or periodontal reasons were collected and stored in phosphate buffered saline (PBS) until use. Each tooth was subjected to a radiological examination to assess the presence of walkable curved canals. Furthermore, a preliminary bidimensional radiographic examination was performed in bucco-lingual and mesio-distal directions to ensure comparative anatomy among teeth. Only those with an angle of curvature ranging from 25° to 40° degrees, according to Pruett et al. evaluation method, were selected (17). Teeth with decay or fractures below the cemento-enamel junction, internal or external resorption, open apices, or previous root canal therapy were excluded. The teeth surface was scraped to clean the soft tissue residues and disinfected with 5% NaOCl solution for 20 min. The cuspids of all teeth were removed until a uniform plain was established to promote a repeatable WL. A diamond bur mounted on a high-speed handpiece equipped with a water-cooling system was used for access cavity preparation. Access was obtained following the design of the traditional access cavities to locate all the canal orifices. Then, each canal's WL was established with a size 10 K-File (Dentsply Maillefer, Ballaigues, Switzerland). The canals were then prepared with Reciproc R25 files (VDW, Dentsply Maillefer, Ballaigues, Switzerland) to the full WL using a 6:1 reduction handpiece (Sirona Dental Systems GmbH, Bensheim, Germany) connected to an electric motor (X-Smart Plus, Dentsply Maillefer) using the Reciproc ALL program (300 rpm, 150° REV–30° FWD) with an up-and-down pecking motion as suggested by the manufacturer. Each instrument was used to prepare only one canal and then discarded.

To ensure a perfect apical seal, the apices of the prepared roots of the teeth were sealed using flowable composite resin (Filtek Flow, 3 M-ESPE, St-Paul, MN, USA). At the same time, the orifices of the untreated canals were sealed with flowable resin composite. Subsequently, each tooth was placed in a stub created with putty-consistency silicone impression material (Zhermack, Badia Polesine, Veneto, Italy) to maintain it vertically in a glass jar. Samples were submerged in 10 mL of PBS and autoclaved at 121 °C for 25 min. Teeth were randomly divided into four groups: A (IrriFlex group), B (Navitip group), and C (Control group).

Laboratory Assessment

An *E. faecalis* strain (BE34) isolated from a chemo-mechanically treated root canal was grown at 37 °C in microaerophilic conditions (5% CO_2) on brain heart infusion (BHI, Oxoid-Thermo Fisher, Italy) broth supplemented with 1.5 % Agar (BD, Italy) and 5% defibrinated horse blood (Liofilchem, Italy). Starter cultures were grown in BHI broth at 37 °C until an OD_{600} of 0.4 and subsequently frozen at -70 °C in BHI with 10% glycerol.

Root Canal Inoculum

Each root canal was inoculated with $5x10^5$ bacterial CFUs of *E. faecalis* BE34 in 10 µl. The bacterial suspension was introduced into the whole length of the canal using an IrriFlex needle mounted on a P20 micropipette, the tip was inserted as deep as possible in the canal, and the suspension was released with a gentle pumping motion. The inoculated teeth were incubated at 37 °C in a 5% CO_2 atmosphere for 21 days [18]. The teeth were randomly allocated into three groups, with 10 specimens in both groups A and B, and 5 specimens in the control group. Initial microbial assessment (S1) was carried out after the incubation period. Each root canal was filled with 20 µL sterile saline solution, and a #20 K-file (Dentsply Maillefer, Ballaigues, Svizzera) was inserted into the root canals to reach the WL with a gentle filling motion. To detach the microorganisms from the inner root surfaces, an ultrasonic tip was placed in contact with the file shank and activated for 1 min; then, the root canals were sampled. Eventually, bacteria were recovered from the root canal using a series of three sterile paper points (size ISO 25, Dentsply), which were, in turn, rubbed against the walls of the root canals (Figure 1). The paper points were allowed to draw up their full capacity of liquid before being transferred into a tube containing PBS with 10% glycerol broth under aseptic conditions and frozen at -70 °C. After this stage, the contaminated vials were exchanged with empty sterile vials.

Figure 1
The image shows the sampling procedure. Sterile paper points were used to collect viable bacteria from the root canals of multirooted extracted teeth.

Irrigation Procedure

Irrigation with 5 ml of 5.25% NaOCl solution at room temperature was performed in groups A and B, respectively, inserting IrriFlex (30 G, 22mm, 0.04 taper) and NaviTip Tip (30 G, 21 mm) (Figure 2). NaviTip Tip was introduced into the canals up to 2 mm from the WL; IrriFlex, after reaching the WL, was retracted by 1 mm before irrigant ejection, according to manufacturer instructions. The irrigant exposure time for groups A and B was 30 seconds. The procedure was performed using digital pressure with the forefinger only, and the needle was gently moved back and forth in the canal, ensuring that the needle did not bind in the canal itself. At the end of irrigation, the canals were rinsed copiously with a sterile saline solution to flush away residual irrigants.

After chemical preparation, samples in groups A and B were irrigated with 5 mL of 5% sodium thiosulfate as a neutralizer and then rinsed with 5 mL sterile saline. Final sampling (S2) was performed using a similar method to initial sampling. *E. faecalis* CFUs were enumerated by plating serial dilutions with a multilayer plating method on BHI agar. The same cohort of teeth was used throughout the experiments, and all irrigation experiments were conducted in triplicate.

Flexibility Test

The equipment used for the test was a customized device (Figure 3) validated in a recently published study (19) with a stainless steel (SS) alloy platform, initially built for Ni-Ti instruments and then adapted for testing irrigation needle tips. In the current study, to eliminate experience variations, the same skilled operator conducted each test. All the needle tips were examined at a 45-degree angle and in three distinct positions: 3, 6, and 9 mm from the tip.

Statistical analysis

The sample size was determined based on the data of a previous study regarding the NaviTip ability to eradicate *E. faecalis* from the root canal system (20). Therefore, a total of 24 samples were indicated as the

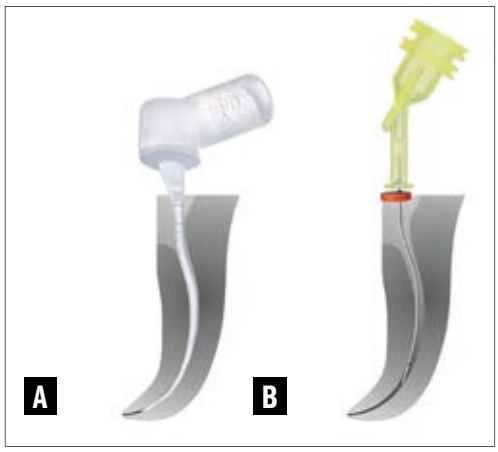


Figure 2
The two tips (IrriFlex and NaviTip Tip) containing NaOCl are visible in this image. IrriFlex is shown on the right (A). NaviTip Tip is shown on the left (B).

ideal size required for noting significant differences using G-Power v3.1 (Heinrich Heine, University of Düsseldorf, Düsseldorf, Germany) by selecting the analysis of variance (ANOVA) test and setting an alpha-type error of 0.05, a beta power of 0.90, and an effect size of 0.80. However, an additional 11 samples (5 for groups A, B, and 1 for the control group) were added to compensate for unexpected values of IrriFlex because there were no data in the literature regarding its ability to eradicate *E. faecalis* strain (BE34). According to this, a total of 35 samples were selected. Data were analyzed using an ad hoc statistical software (STATA BE, version 17.1, StataCorp LP, TX, USA), setting the level of significance at α=0.05. After verification of data distribution using Shapiro-Wilk test, Kruskal-Wallis test was conducted to assess the overall differences in CFU and flexibility among the three groups. Dunn test was used for pairwise comparison.

Results

Irrigation procedure

A mean of $7.8x10^4$ CFUs of *E. faecalis* BE34 was recovered from the control samples, while the use of NaviTip and IrriFlex produced a reduction in bacterial viability below the limit of detection of 2.5 CFUs (Figure 4) without a statistical difference between the two irrigation needles ($p > 0.05$) (Table 1). The bacterial load recovered from control samples was slightly lower than the actual inoculum of $5x10^5$ CFUs. Bacterial viability was significantly reduced after NaOCl irrigation using NaviTip and IrriFlex compared to controls. The mean log CFUs of 5.89 reported for untreated teeth turned out to be much higher compared to the test groups, as shown in Table 1.

Flexibility test

The results of the flexibility test are shown in table 2. Statistical analysis showed:
No significant difference between NaviTip and IrriFlex at 3mm and 6mm.
A significant difference between NaviTip and IrriFlex at 9 mm.

Discussion

The aim of the current study was to assess how two different endodontic irrigation

Table 1

***E. faecalis* count after root canal irrigation expressed in mean log CFU**

Needles	Bacteria Recovered (mean log CFU)	N	Standard Deviation	Variance
Control group	5.89	5	34.94	1220.87
IrriFlex	1.25	15	-	-
NaviTip	1.25	15	-	-

Abbreviations: CFU, colony-forming units; N, number of samples per group

Table 2

Results of the flexibility test conducted at three distinct positions from the instrument tips: 3, 6, and 9 mm

Needles	Flexibility [grams] (mean ± standard deviation)		
	3mm	6mm	9mm
NaviTip Tip	13.6 ± 1.14*	24.2 ± 2.59*	35.8 ± 3.11†
IrriFlex	9.4 ± 1.81†	26.8 ± 2.77†	55.2 ± 4.66†

**,† In each column, means sharing the same symbol are related by a statistically significant difference (P<0.05).*

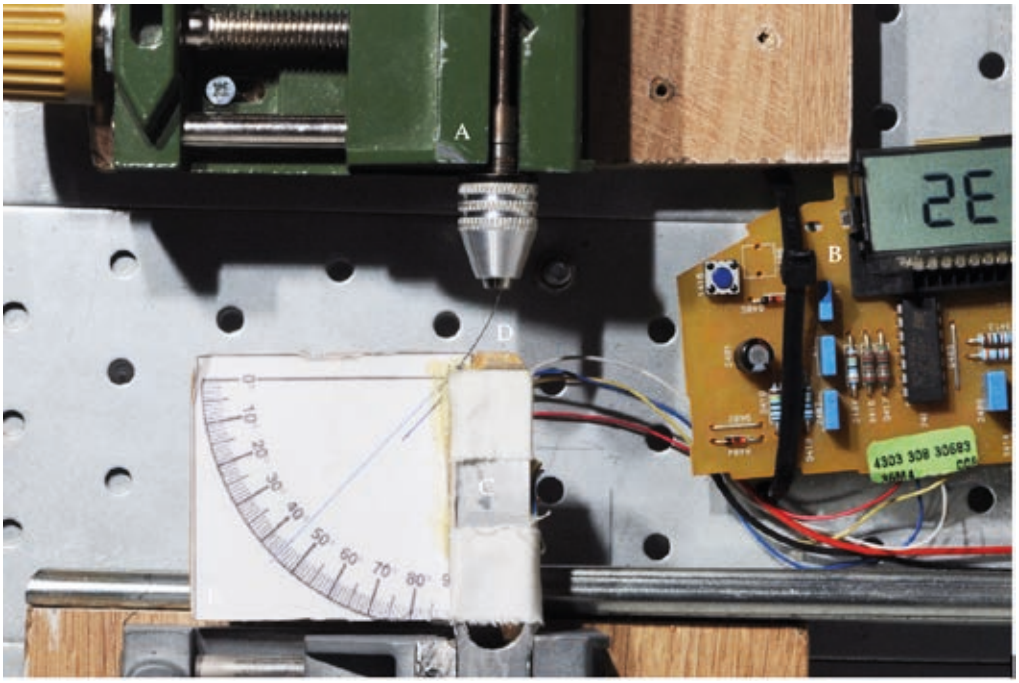
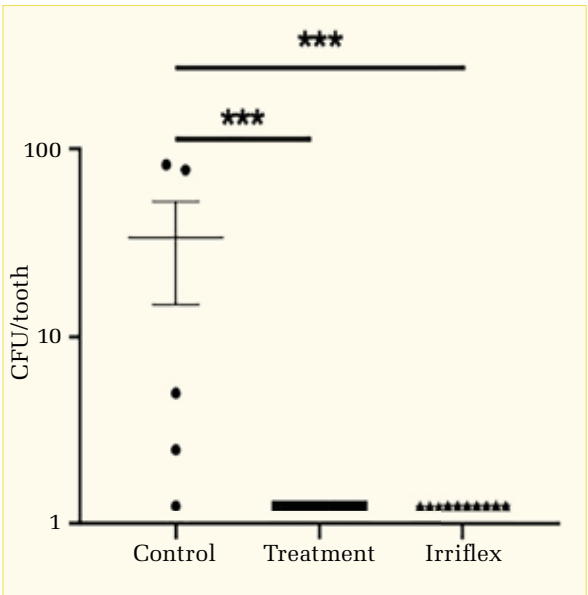


Figure 3
Bending device. A load cell (C) connected to a digital display (B) was put on a stainles-steel platform, together with an analog protractor (E) and a mobile device that enabled reproducible positioning of the needle tip (A, D) on the load cell. The analog protractor measured various bending angles, while the mobile device measured the bending resistance at multiple points on the tip (3 mm, 6 mm, 9 mm).

needles affected the elimination of *E. faecalis* from curved canals of multirooted teeth contaminated *in vitro* with *E. faecalis*. The two tested needles were IrriFlex (flexible double-sided polypropylene needles) and NaviTip Tips (open-ended steel needles). Additionally, the study tested and compared the flexibility of these needle tips at three different positions from their extremities: 3 mm, 6mm, and 9 mm. The first null hypothesis was accepted as no statistically significant difference emerged between NaviTip and IrriFlex (Table 1). However, the second null hypothesis was only partially rejected because irriFlex showed a higher but not significant banding ability at 3 and 6 mm (Table 2). On the contrary, at 9 mm, a statistically significant difference was highlighted with NaviTip demonstrating greater flexibility compared to IrriFlex. This difference was attributed to their varying taper, which impacts the bending ability of the needle tip in the coronal third.

Figure 4
Mean count in CFUs. Bacterial viability after passive irrigation using NaviTip and IrriFlex compared to controls.



Effective infection control during endodontic treatment requires direct contact between the irrigant and the entire canal wall surface, particularly in the apical region (21). To fulfil this requirement, an effective delivery system is necessary (10). In the current study, both NaviTip and IrriFlex systems demonstrated a comparable capacity to significantly reduce bacterial counts below the positivity threshold.

These results align with a recent study conducted on single-rooted teeth, which demonstrated that both NaviTip and IrriFlex are more efficient at removing mature bacterial biofilms compared to another needle, with a slight but not significant advantage for IrriFlex (4). Methodological differences, such as the choice of different E. faecalis strains with a two-week-old biofilm and viability assessment, may have contributed to this slight variation in results. IrriFlex and NaviTip bending abilities allow the needle tip to easily reach the apex in case of important canal curvatures

(10). Current literature suggests that the extrusion of the irrigant close to the WL results in a more efficient irrigation (6). The current study demonstrated that IrriFlex is slightly more flexible than NaviTip without showing a statistically significant difference, this result confirms their comparable efficacy in CFUs reduction.

E. faecalis mature biofilms are frequently used as a model of endodontic infection in *ex vivo* studies (4). They have been employed in several previous studies to evaluate the effectiveness of endodontic irrigants (22). This Gram-positive bacterium can proliferate without synergistic support from other bacteria and survive under extended periods of nutrient deficiency, even after mechanical and chemical root canal preparation, due to its ability to form biofilm and penetrate dentinal tubules (2). However, recent studies have raised questions about its actual role in post-treatment apical periodontitis (23,24), demonstrating that it is often absent and, when detected, it is not among the most prevalent species (1). Nevertheless, *E. faecalis ability* to thrive under various growth conditions makes it a convenient model for laboratory research (22). In the present study, the clinical strain BE18 was employed because resistant to chemo-mechanical preparation (27).

The exposure time of the irrigant in this study appears to be shorter than what is typically used in clinical practice. Although, Dunavant et al. showed that the amount of *E. faecalis* elimination is not significantly affected by an exposure time ranging from 1 to 5 minutes (27).

Regarding the concentrations of NaOCl, there is no consensus, and values ranging from 0.5 to 8.25% are commonly used for root canal irrigation (28). Laboratory studies indicated that the effectiveness of NaOCl is related to its concentration (22). A recent systematic review demonstrated, with weak evidence, that higher concentrations may ensure an advantage (29). Nevertheless, recent clinical studies have not found a significant difference in the antimicrobial effect among different NaOCl concentrations(30,31). Verma et al. found no difference in healing after endodontic treatment when using 1% or 5.25% NaOCl for root canal irrigation (30). In the current study, a 5.25% NaOCl solution was used because it was demonstrated that higher concentrations of NaOCl reduce the time required to lower viable counts below the limit of detection (32). Moreover, *E. faecalis* was significantly more resistant to NaOCl (0.5, 1.0, 2.5, and 5.25%) when compared with the other species tested (*Actinomyces naeslundii*, *Candida albicans*) (32) . Additionally, in the present study, no irrigant activation was performed despite being the gold standard in order to effectively validate the disinfection ability of the two needles, excluding any other factors able to influence it.

The primary outcome in endodontics is the prevention or healing of apical periodontitis (14); However, the lack of evidence on root canal irrigation is probably due to the complexity of measuring this primary outcome (22). Authors often prefer to use surrogate end-points, which are easier to measure. The reduction of the intracanal microbial load is undoubtedly the most relevant surrogate end-point to study irrigants and irrigation systems (22) due to the critical role of bacteria in the development of pulpal and periapical diseases. In single-rooted teeth, this end-point is linked to the healing of apical periodontitis, and there was a need to prove these findings also in posterior teeth (22).

The use of extracted teeth in this study, previously employed in other research comparing various irrigation systems and solutions, provided better control over endodontic system contamination (12). Clinical studies, while representing a higher level of evidence, are subject to variations between teeth and uncontrollable parameters, acting as potential confounders (12). The efficiency of new irrigation systems or irrigants should not be immediately tested by *in vivo* studies. Instead, *in vitro* and *ex vivo* studies with rigorous control of confounders should be performed in order to select the appropriate candidates for *in vivo* studies (22).

Standardizing the insertion depth of the needle tip is essential (22), as it has been demonstrated in some previous studies on

the binding point of these components inside the root canal (22). However, the variability of this point may differ even in root canals with the same apical size and taper (33). Therefore, it is advisable to use the apical end of instrumentation as a reference to define the insertion depth (22). The constant in-and-out movement of these components within the root canal, as applied by some clinicians, is difficult to standardize in laboratory studies without the use of robotic arms (33).

While paper points can be employed for sampling when the biofilm is grown inside a root canal, they have limitations (22). Paper points can only detach planktonic bacteria from the root canal lumen and those bacteria that are only loosely adherent to the wall (22). Therefore, this sampling procedure excludes all the bacteria remaining in isthmuses, lateral canals, and other anatomic irregularities that are difficult to reach with instruments and irrigants (4). Furthermore, the vortexing movement used to recover the sampled bacteria with the paper point causes a loss of information on the exact localization of the bacteria in the root canal (2).

An additional limitation of our study was the use of a mono-species biofilm model. Although E. faecalis is often found in natural biofilm communities with multiple microorganisms, we opted for a mono-species model to ensure protocol simplicity and standardization. Multi-species biofilm models, despite their closer resemblance to real-life conditions, present challenges in managing competitive interactions among bacterial species. Indeed, to date no valid methods exist to manage each bacterial species within a multispecies biofilm (4).

Another weakness of the present study is the assessment of bacterial viability in our study relied on culture methods, which quantify only viable, cultivable bacteria by plating on agar plates (22) and quantifying CFUs. However, only viable bacteria, able to divide and form colonies, were quantified through this approach (22). In root canal infections, many bacteria are viable but non-culturable (VBNC), meaning that despite their inability to grow in culture media, they are virulent, metabolically active, and able to form a biofilm, although to a lesser degree than viable bacteria (22). To address these limitations, further experimental and clinical studies are necessary to better assess the efficacy of new devices in eradicating *E. faecalis* from canals with complex anatomy and establish a more direct link with clinical practice.

Conclusions

The results demonstrated that both irrigation systems effectively reduced the bacterial load, with no statistically significant differences between them. Although IrriFlex exhibited greater flexibility, there was no significant difference between the two tips at 3 and 6 mm.

Clinical Relevance

This study compared IrriFlex and NaviTip irrigation needles in eliminating E. faecalis from curved root canals. . Both IrriFlex and NaviTip Tip demonstrated comparable efficacy, significantly reducing E. faecalis colony-forming units. Additionally, IrriFlex exhibited higher flexibility at 3 and 6 mm compared to NaviTip. The findings suggest both needles are effective in bacterial removal, with IrriFlex offering enhanced flexibility, crucial for navigating complex canal systems.

Conflict of Interest

The authors declare no conflict of interest

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ORIGINAL ARTICLE

Apical transportation and surface characteristics of thermally-treated reciprocating instruments after endodontic reintervention

ABSTRACT

Aim: *To evaluate the apical transportation and surface characteristics of two thermally-treated reciprocating instruments after endodontic reintervention.*
Methodology: *Images of 42 resin blocks containing simulated canals were obtained. After instrumentation (WaveOne Gold Primary - 25.07), the simulated canals were obturated and new images were obtained. The blocks were distributed into two groups (n=21), WaveOne Gold (Medium - 35.06) and Reciproc Blue (R40 - 40.06). Each instrument was used for filling material removal and re-instrumentation of three simulated canals. After reintervention, new images of the blocks were obtained and superimposed on the initial ones to calculate the apical transportation. The surface characteristics of the instruments before and after continuous use were performed under [Scanning Electron Microscope (SEM)]. The Kruskal-Wallis test was applied to the data and complemented by Dunn's multiple comparison test (p<0.05).*
Results: *Both systems had similar apical transportation values, with no significant difference (p>0.05). WaveOne Gold with no use and after the first use showed a greater number of defects than Reciproc Blue with no use and after two uses (p<0.001). Reciproc Blue had a significant increase in the number of defects after the third use (p<0.001).*
Conclusions: *WaveOne Gold and Reciproc Blue systems provided minimal and similar apical transportation. The number of defects was greater for the WaveOne Gold system, which increased after endodontic reintervention.*

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Introduction

The main cause of endodontic treatment failure is persistent infection after chemical-mechanical preparation (1). As an alternative treatment for these cases, non-surgical endodontic reintervention should be considered the first choice (2). Therefore, the filling material must be removed, and new instrumentation and obturation of the root canal system performed (3).

Several techniques have been proposed for the filling material removal during endodontic reintervention (4, 5). Rotary and reciprocating instruments made from thermally-treated Ni-Ti alloy have shown great effectiveness (6, 7). Nevertheless, no technique or instrumentation system is capable of completely removing the obturation, leaving remnants of filling material attached to the root canal walls (4, 5). Furthermore, these instruments promote changes in the original root canal trajectory during filling material removal and re-instrumentation, especially in curved canals (8). For this reason, new instruments with modified cross-sections, asymmetrical motion, and advances in the thermomechanical treatment of Ni-Ti alloys have been proposed to maintain the original root canal shape (9, 10).

The instruments of the WaveOne Gold (Dentsply Maillefer, Ballaigues, Switzerland) and Reciproc Blue systems (VDW, Munich, Germany) are manufactured from specific thermally-treated Ni-Ti alloys (11). WaveOne Gold instruments have a two-dimensional parallelogram cross-section and variable taper (12), while Reciproc Blue instruments have an S-shaped cross-section with a regressive taper in the first three apical millimetres (13). Both are single-file systems, and according to their respective manufacturers, they must be used to prepare a maximum of three to four canals in the same patient. The continuous use of these instruments leads to their wear and deformation, increasing the risk of fracture (14, 15).

These instruments are submitted to a high level of stress during filling material removal and re-preparation, especially in multi-rooted teeth with curved canals (3, 4). Few studies have evaluated the changes in root canal morphology, such as apical transportation, after endodontic reintervention (16). Moreover, no study so far has assessed the topographic changes that may occur on the surface of these instruments after their continuous use.

The purpose of this *in vitro* study was to evaluate the apical transportation promoted by these two thermally-treated reciprocating instruments (WaveOne Gold and Reciproc Blue) during endodontic reintervention in simulated curved canals. The analysis of the surface characteristics of these instruments was also performed after their continuous use (filling material removal and re-preparation of the simulated canal). The null hypotheses tested were that there would be no difference between the different instrumentation systems regarding I) the apical transportation and II) the surface characteristics of the instruments after endodontic reintervention.

Materials and Methods

Simulated Root Canal Preparation and Obturation

The manuscript of this laboratory study has been written following the Preferred Reporting Items for Laboratory studies in Endodontology (PRILE) 2021 Guidelines (17) (Figure 1). In the present study, we used forty-two transparent blocks of polyester resin (IM do Brasil Ltda. São Paulo, Brazil) containing simulated canals with an angle of 40°, a radius of curvature of 3 mm, and 17 mm in length. The sample size was determined based on data from a pilot study. A bilateral test for associated samples (level of significance=0.05% and test power=0.85), recommended 42 samples.

Initially, the simulated root canals were prepared with the Primary instrument (25.07) of the WaveOne Gold system (Dentsply-Maillefer). The instrument was coupled to a 6:1 contra-angle device powered by an electric motor (X-Smart Plus, Dentsply-Maillefer), driven in a reciprocating motion, and introduced into the canal with light pressure in the apical direction, in back-and-forth movements, and maximum

amplitude of 3 mm. During the preparation of the cervical and middle thirds, the canal was irrigated with 1 mL of 2.5% NaOCl solution (Rio Química, São José do Rio Preto, Brazil), at each advancement and removal of the instrument for cleaning in sterile gauze. The irrigating solution was placed into the simulated canal with a 5-mL syringe (Ultradent, Salt Lake City, USA) and a 27-g needle (Endo-Eze; Ultradent) using back-and-forth movements. After, the working length was determined with a size 10 K-type instrument (Dentsply-Maillefer), inserted into the simulated canal in the apical direction until the tip was visualized at the apical foramen. The working length was set at 1 mm short of the apical foramen (16 mm). The apical finishing was performed as for the other root canal thirds until reaching the working length. At every three simulated canals prepared, the instrument was replaced by a new one, as recommended by the manufacturer.

After completion of the chemical-mechanical preparation, the simulated canals were obturated with gutta-percha cones (WaveOne Gold Primary; Dentsply-Maillefer) and an epoxy resin-based root canal sealer (AH Plus; Dentsply, Petrópolis, Brazil) by the Tagger's hybrid technique. The integrity of the obturation was meticulously visually inspected with the aid of magnifying glasses (×2.5). In instances where the artificial canal obturation exhibited bubbles, voids, and failures in the compaction of the filling material (18), the specimen was discarded from the final sample and replaced with a new resin block. The resin blocks were stored for seven days until the final setting of the root canal sealer.

Collection of Instruments and Scanning Electron Microscopy (SEM)

Seven brand-new instruments from the WaveOne Gold (Medium - 35.06) (Dentsply-Maillefer) and Reciproc Blue systems (R40 - 40.06) (VDW) were removed from their packaging materials and meticulously inspected under magnification (×4). Only instruments free of visible defects and irregularities were included in the study. The WaveOne Gold system instruments were numbered from 1 to 7, and the Reciproc Blue system instruments were numbered from 8 to 14. No previous cleaning treatment was performed on the instruments. The instruments were carefully handled with clinical forceps during all stages of this research, avoiding contamination by other materials that might compromise the analysis of their surface characteristics. The instruments were placed on metal stubs for initial assessment of their topography and surface characteristics under [Scanning Electron Microscopy (SEM)] (Jeol, JSM-IT500HR, Peabody, USA). Images from both sides of the active part of the instruments were obtained. The active part of each instrument was assessed at ×190 magnification, in three different portions: instrument tip, 2 mm, and 4 mm short of the instrument tip.

Endodontic Reintervention

After the initial SEM images acquisition, each one of the seven instruments of the tested systems was used for the filling material removal and re-instrumentation of three resin blocks containing the previously obturated simulated root canals. The resin blocks containing the simulated root canals were randomly distributed into 2 groups (n=21) (Random Sequence Generator; https://www.randomdraws.com/random-sequence-generator), according to the instrumentation system used for endodontic reintervention: WaveOne Gold (Medium - 35.06) and Reciproc Blue (R40 - 40.06). The same protocol for filling material removal and re-preparation was used for both systems.

Initially, each instrument was coupled to a 6:1 contra-angle device driven by an electric motor (X-Smart Plus, Dentsply-Maillefer), at 400 rpm, in a reciprocating motion. For the filling material removal and re-instrumentation of the simulated canal, each instrument was gradually inserted into the root canal three times, in the apical direction, with gentle pecking movements of a 3-mm amplitude limit. At each instrument removal for cleaning, 2 mL of 2.5% NaOCl solution (Rio Química) was used for root canal irrigation. The irrigating solution was placed into the simulated canal with a 5-mL syringe (Ultradent) and a 27-g needle (Endo-Eze; Ultradent) inserted to 2 mm short of working length using back-and-

During endodontic reintervention, instruments are subjected to a high level of stress. Few studies have assesseed the apical transportation after cyclic use of thermally-treated reciprocating instruments. Furthermore, no study so far has assessed the topographic changes that may occur on the surface of these instruments after their continuous use.

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The sample size was determined based on data from a pilot study. A bilateral test for associated samples (level of significance=0.05% and test power=0.85), recommended 42 samples.

Image of 42 resin blocks containg simulated canals were obtained. After preparation (WaveOne Gold Primar -25.07), the simulated canals were obturated and new images were obtained.

The resin blocks containg the simulated wew distrbuted into two groups (n=21): WaveOne Gold (Medium-35.06) and Reciproc Blue (R40-40.06).

After reintervention, new images were obtained supeimposed on the initial ones to calculate the apical transportation (ImageJ software; https://imagej.nih.gov/ij/download.html). The surface characteristics of the instruments before and after continuos use were assesse under Scanning Electron Microscope (SEM).The Kruskal-Wallis and Dunn's multiple comparision test were applied to the data (p>0.05).

Both systems had similar apical transportation (p>0.05). WaveOne Gold with no use and after the first use showed a greater number of defects than Rec1procB lue with no use and after two uses (p<0.001). Reciproc Blue had a significant crease in the number of defects after the third use (p<0.001).

WaveOne Gold and Reciproc Blue systems provided and similar apical transportation: the number of defects greater for the WaveOne Gold system, which increased after endodontic reintervention.

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

Figure 1 PRILE flowchart.

forth movements. These procedures were repeated until the instrument reached the working length (16 mm), and it was no longer possible to visualize filling material inside the simulated canal, in the active part of the instruments, and/or in suspension during the irrigating solution reflux. At the end of the simulated root canal re-instrumentation, a final irrigation protocol with 5 mL of 2.5% NaOCl solution (Rio Química) was performed. The simulated root canal preparation and re-preparation were performed by only one experienced Endodontics specialist to avoid any variables regarding the shaping ability of different operators.
At the end of each endodontic reintervention, the instrument was cleaned in an ultrasonic bowl (Cristófoli, Campo Mourão, Brazil) containing heated water and enzymatic detergent (Endozime; Medclean Comercial Ltda., Porto Alegre, Brazil) and submitted to a new SEM images acquisition, as previously described. After completion of the endodontic reintervention in the last block (third), the instrument was once again cleaned, and new SEM images were acquired.

SEM Analysis
To minimize the risk of bias, the analysis of the images obtained under SEM before and after endodontic reintervention was performed at different times, with an interval of 15 days between each one. The images were assessed by two previously calibrated and blinded examiners. The findings observed at different times were submitted to the Kappa test to assess intra- and inter-examiner agreement, until the establishment of rates greater than 0.7 for validation and reproducibility. The analysis of the surface characteristics of the instruments was performed at the same angle as the active part of the instruments, comparing the images obtained before and after their continuous use. The findings considered during the analysis were: active part of the instrument with irregular edges, grooves, microcavities, burrs, and/or debris attached to the instrument's surface (14, 15). A scoring system based on the number of defects present on the instrument's surface was used (14, 15) (Table 1).

Apical Transportation Analysis
For the apical transportation analysis, each resin block was photographed in a standardized manner, at two different times: after simulated root canal obturation and after endodontic reintervention. A digital camera (Canon EOS Rebel T5, Lake Success, USA), with a resolution of 18 megapixels, a macro lens of 100 mm, and a diaphragm opening of 4.5 was used for image acquisition. To standardize the distance between the camera lens and the resin block, the simulated root canals were positioned on a platform in the same position, at a focal distance of 32 cm. All pictures were taken under the same conditions, under ambient light.
With the aid of the ImageJ software (https://imagej.nih.gov/ij/download.html), the images of the simulated root

Table 1

Scoring system used to assess the presence of defects on the surface of instruments.

Score	Defects on the surface of instruments
1	Long axis of the instrument without any defect on its surface.
2	Long axis of the instrument with one to three areas of defects on its surface.
3	Long axis of the instrument with four to five areas of defects on its surface.
4	Long axis of the instrument with more than five areas of defects on its surface.

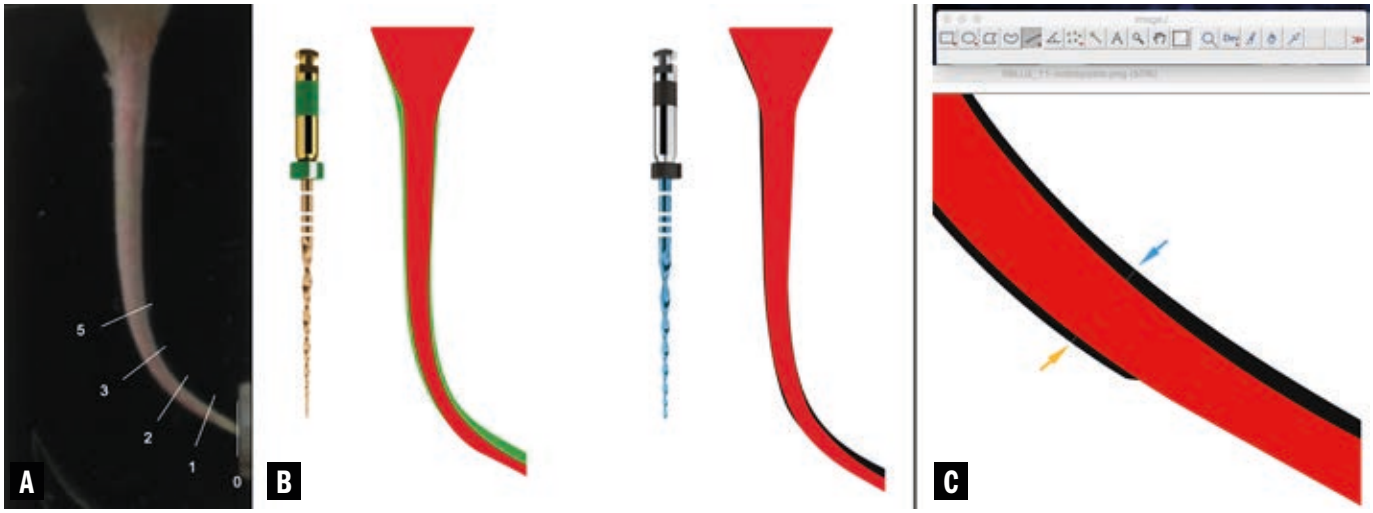

Figure 2
A) Resin block containing the simulated root canal. Measuring ruler for the four evaluated apical levels (mm). **B)** Superimposed images of the simulated root canals before (red) and after endodontic reintervention (green - WaveOne Gold and black - Reciproc Blue). **C)** Measurements on the outer surface (yellow arrow) of the root canal to the inner surface (blue arrow) (ImageJ software).

canals received different colours. Red for the obturated root canals (before endodontic reintervention), green for the root canals re-instrumented with the WaveOne Gold system, and black for the root canals re-instrumented with the Reciproc Blue system. The Adobe Photoshop CC (Adobe Systems Inc., San Jose, USA) software was used to superimpose the final images over the initial ones. The distance from the inner wall of the obturated root canal to the outer wall of the post-reintervention root canal was measured blindly by a single calibrated and trained examiner, with the ImageJ software. The equation AT=IS-OS was used to calculate the apical transportation of the simulated root canal, where IS represents the wear on the inner surface of the canal, and OS, the wear on the outer surface. The apical transportation was measured in four different reference points, corresponding to the 1st, 2nd, 3rd, and 5th millimetres below the root apex (Figure 2).

Statistical Analysis

The GraphPad InStat software (GraphPad Software, La Jolla, USA) was used to perform the statistical analysis. The dataset for apical transportation did not have a normal distribution (The Shapiro-Wilk

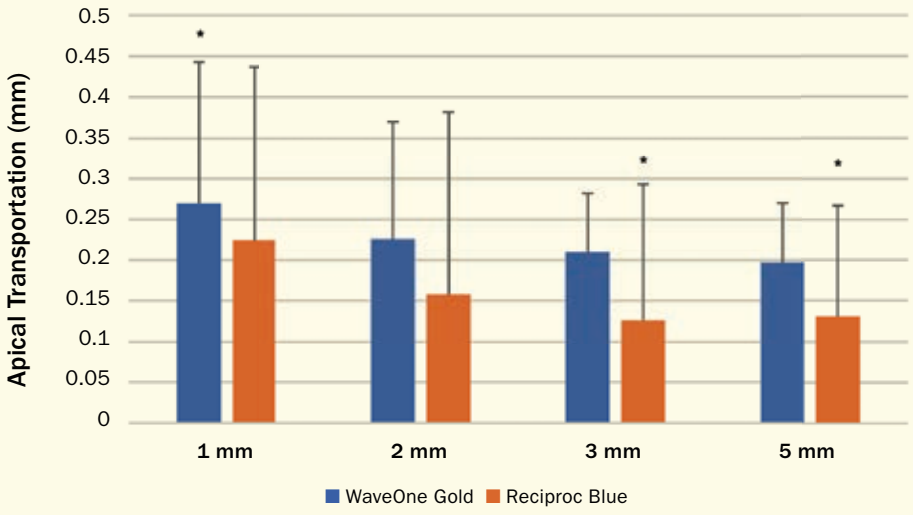

Figure 3
Graphic representation of apical transportation mean values (mm).
**Over bars indicate a statistically significant difference (the Kruskal-Wallis and Dunn's multiple comparison tests, p<0.05).*

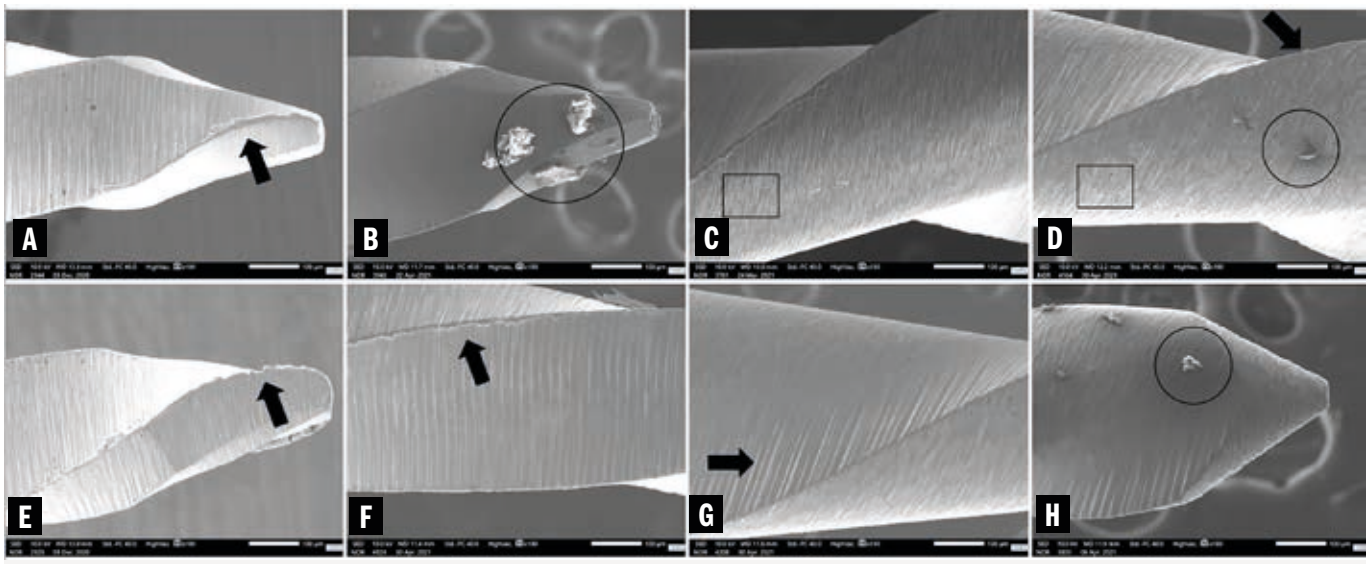

Figure 4
Representative SEM images of the active part of the instruments before and after continuous use. **A)** An irregular edge-like defect on the tip of the WaveOne Gold instrument before use (arrow), **(B)**, and after the second use. Note the presence of attached debris on the tip of the instrument (circle). **C)** Microcavities were observed in the Reciproc Blue instrument after the first and **(D)** third use (boxes). It is also possible to observe the presence of attached debris (circle) and irregular edge (arrow). **E)** A burr-like defect on the tip of the WaveOne Gold instrument after the first use and **(F)** after the third use (arrows). **G)** Perpendicular marks of the machining process (grooves) on the surface of the WaveOne Gold instrument before use (arrow). **H)** Attached debris on the Reciproc Blue instrument after the second use. (SEM×190).

test, $p>0.05$) and homogeneity of variance (The Levene test, $p>0.05$). The Kruskal-Wallis test for the independent factors, apical distance, and instrumentation system, was initially applied to the data, complemented by Dunn's multiple comparison tests ($p<0.05$). For the surface characteristics changes in the instruments, the Kruskal-Wallis test ($p<0.05$) was also performed. Statistically difference between groups was considered when $p<0.05$.

Results

Apical Transportation
The mean values (mm) for apical transportation (Figure 3). In general, WaveOne Gold and Reciproc Blue systems had similar apical transportation values, with no significant difference ($p>0.05$). However, when the apical distance was considered, WaveOne Gold at the 1st mm had greater apical transportation than Reciproc Blue at the 3rd and 5th mm ($p<0.001$).
Regarding the direction of apical transportation, both instrumentation systems had a greater tendency towards transport to the inner surface of the simulated root canal than towards the outer surface.

Analysis of Defects and Deformations on Instruments Surfaces
Representative SEM images of the active part of the instruments may be seen in (Figure 4). The incidence of defects and deformations (irregular edges, grooves, microcavities, burrs, and attached debris) observed on the instrument's surface before and after continuous use is in (Figure 5). There were defects and deformations in all instruments, before and after continuous use (endodontic reintervention). WaveOne Gold always had a higher prevalence of irregular edge defects. On the other hand, there was a decrease in this type of defect according to the continuous use of instruments from both systems. Grooves were observed in the active part of the instruments after endodontic reintervention. However, when the times of use were compared, WaveOne Gold had a greater number of grooves after the second use. Conversely, Reciproc Blue had a greater amount of this defect after the first use.

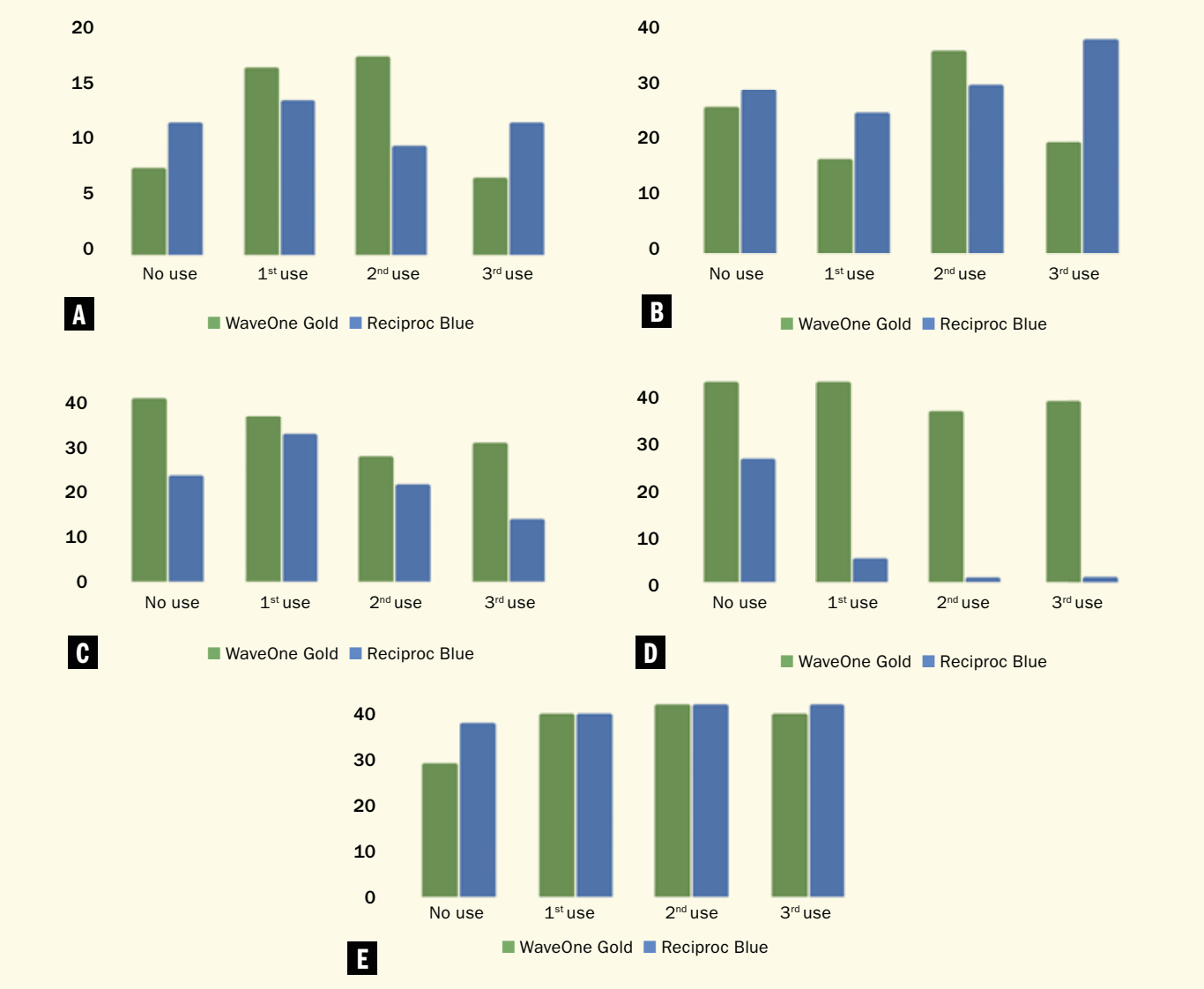

Figure 5
Incidence of defects on instrument surfaces before and after continuous use at the instrument tip, 2 mm, and 4 mm short of the instrument tip. **A)** Grooves. **B)** microcavities, **C)** irregular edges, **D)** burrs, **E)** attached debris (SEM×190).

Regarding the presence of microcavities, Reciproc Blue presented this defect even before the first use, which increased after the first and third use. WaveOne Gold presented this defect only after its second use. The same was observed for the presence of burrs in the active part of the instruments. Reciproc Blue presented this defect before the first use, increasing its prevalence after continuous use. The number of burrs observed in WaveOne Gold was smaller than in Reciproc Blue. At all periods of analysis, the presence of debris attached to the active part of both instrumentation systems was observed. For the WaveOne Gold, the amount of this defect was lower in comparison with the Reciproc Blue.

The results of the topographic changes on the instrument's surface, according to the scoring system used, are in (Figure 6). Reciproc Blue had a statistically significant increase in the number of defects and deformations after the third use ($p<0.001$). WaveOne Gold with no use and after the first use had a higher number of defects and deformations than Reciproc Blue with no use and after two uses ($p<0.001$). After the second use, WaveOne Gold had a higher number of defects and deformations than Reciproc Blue with no use and after two uses ($p<0.001$).

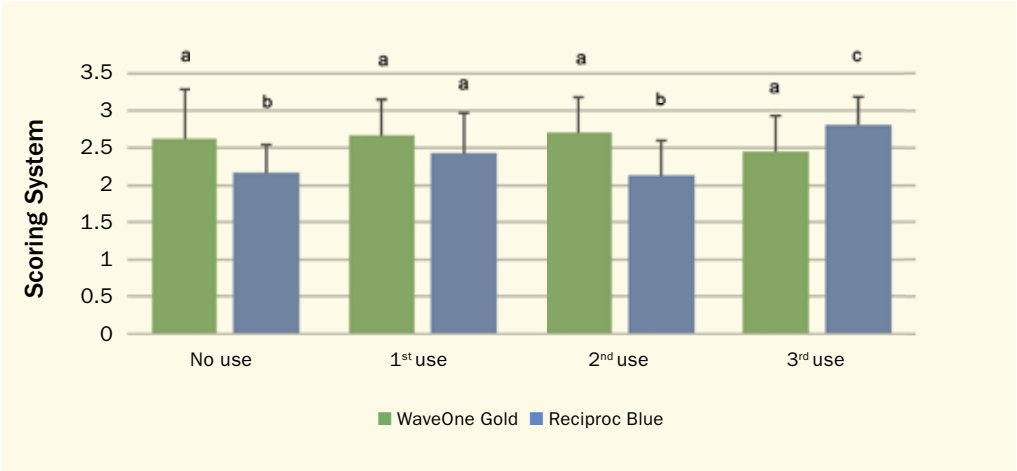

Figure 6
Graphic representation of mean scores of the defects observed on the instrument's surface before and after continuous use. Different lowercase letters over bars indicate a statistically significant difference (the Kruskal-Wallis test, p<0.05).

Discussion

The present *in vitro* study evaluated the apical transportation promoted by two thermally-treated reciprocating instruments, WaveOne Gold and Reciproc Blue, during endodontic reintervention. The change in the surface characteristics of these instruments after their continuous use was also evaluated. Based on the results obtained, the first null hypothesis was accepted, since both systems provided similar apical transportation. The second null hypothesis tested was rejected, as the instruments had significant changes in their surface characteristics after endodontic reintervention.

This laboratory study is the first to evaluate the performance of WaveOne Gold and Reciproc Blue instrumentation systems during endodontic reintervention. According to their manufacturers, both systems must be used to prepare three to four root canals in the same patient. Therefore, the present research aimed to mimic a clinical scenario in which the shaping ability and the changes in surface characteristics of these instruments were assessed after endodontic reintervention of a molar tooth containing three root canals. The maintenance of the anatomical path of the root canal plays a key role in the success of endodontic treatment, especially in root canals with accentuated curvatures.

Human teeth are widely used to perform dental research (19-21). Conversely, obtaining a great number of human teeth in proper conditions for laboratory use is a hard-to-reach condition, especially because of the ethical concerns involved (19-21). Therefore, finding a proper substitute for human teeth is crucial to conduct clinical-relevant studies (19-21). Despite the inherent limitations of an in vitro study, the use of resin blocks containing simulated root canals and superimposition of images before and after instrumentation is a widely accepted method for assessing apical transportation (19-21). The main advantage of this method is sample standardization (19, 22). Other methods can evaluate the root canal morphology in 3-D, such as cone beam computed tomography and micro-CT (13, 23). However, in these methodologies, large amounts of human teeth are required for pairing and standardization of the final sample, in addition to the high cost of the equipment. Thus, such methodologies reinforce the need for reliable human teeth substitutes, such as the resin block containing simulated root canals.

To avoid the accumulation of acrylic resin debris inside the simulated canals, copious irrigation with NaOCl solution was performed during instrumentation, filling material removal, and re-instrumentation of the canals. In addition, constant irrigation reduced the heat generated by the friction of the instruments against the resin walls of the simulated canal (20). The heat produced in the simulated canal by the action of the instruments may lead to softening of the resin, followed by cutting

blade binding in the canal walls and separation of the instrument (20). In the present study, no instrument was fractured during the endodontic reintervention. To measure the apical transportation after endodontic reintervention, four reference points were established, corresponding to the 1st, 2nd, 3rd, and 5th millimetres below the root apex. Our results showed that no instrumentation system was able to maintain the original trajectory of the simulated root canal, causing minimal transportation at the different levels (apical distance), corroborating the studies by Orel et al. (19) and de Silva et al. (21).

Regardless of the apical distance, there was no statistically significant difference between WaveOne Gold and Reciproc Blue system regarding the apical transportation produced after the endodontic reintervention. These results agree with other studies that have shown that both instrumentation systems have similar shaping abilities (24, 25). On the other hand, Orel et al. (19) have reported that WaveOne Gold produced lesser apical transportation than Reciproc Blue. According to these authors (19), this fact may be associated with a greater centring ability of this instrumentation system when compared to Reciproc Blue. The ability of an instrument in remaining at the centre of the root canal space plays a key role in the proper shaping of the root canal (26). Conversely, when the apical distance was considered in the analysis, WaveOne Gold at the 1st mm had greater apical transportation than Reciproc Blue at the 3rd and 5th mm.

Regarding the amount of resin removed from the interior and/or exterior walls of the resin blocks, both instrumentation systems tend to cut more on the inner wall of the simulated root canals. However, it is worth noting that, on average, the apical transportation promoted by WaveOne Gold and Reciproc Blue was not greater than 0.3 mm. From a clinical point of view, such apical transportation value is considered acceptable, with a favourable prognosis (25, 27).

Furthermore, it is important to emphasize that in all the studies cited above, apical transportation was assessed post-root canal preparation and not post-endodontic reintervention, in which the filling material removal and root canal re-instrumentation are necessary. This experimental condition proves the novelty of the present research and the importance of its findings.

Besides the shaping ability analysis, in the present study, changes in the topography and surface characteristics of the instruments were assessed under SEM after their continuous use. Studies demonstrated SEM accuracy in assessing possible changes on the surface of metallic materials, such as endodontic instruments (14, 15). WaveOne Gold showed defects and deformations even before being used. Conversely, for the Reciproc Blue instrumentation system, the changes in its surface characteristics were more evident only after the third use. Despite these differences, this fact did not correlate with apical transportation since both systems had similar shaping abilities.

Thermally treated Ni-Ti instrumentation systems had phase transformation changes to increase their physical properties (martensitic instruments), such as flexibility and mechanical resistance (28, 29). According to Keskin et al. (29), Reciproc Blue has greater cyclic fatigue resistance than WaveOne Gold. This difference may be associated with the instrument manufacturing process (29). The Reciproc Blue instruments are manufactured from a Ni-Ti alloy coated by an oxide layer using a thermomechanical process (29). WaveOne Gold is manufactured from Gold-wire because of an advanced metallurgical process followed by heating, which produces instruments with high ductility (29). Despite being considered martensitic instruments, with high flexibility, Martins et al. (30) have reported these differences in the phase transformation temperatures for WaveOne Gold and Reciproc Blue systems. However, in their study, the fracture resistance of both

systems was similar. The instruments used in the present study were brand new. However, several defects were observed along their active part even before use, especially for the WaveOne Gold system. The metallurgical process to fabricate the instruments may lead to a concentration of debris along their surfaces (15, 16). The presence of this debris even before use may lead to a faster surface deterioration when instruments are submitted to high levels of stress, as during endodontic reintervention (16). This phenomenon was observed for the WaveOne Gold instrument, as the continuous use produced an increase in surface defects for the Reciproc Blue instrument only after its third use. Although the amount of remaining filling material attached to the artificial canal after endodontic reintervention was not assessed in the present study, it is valid to emphasize that no instrumentation system is capable of entirely eliminating the obturation (2-5, 31). The remaining filling material may serve as a potential reservoir for microorganisms, thereby compromising the efficacy of non-surgical endodontic reintervention (1). Consequently, the utilization of instruments with greater taper should be considered for the removal of filling material, followed by root canal re-instrumentation, to achieve maximal removal of the filling material (16). Therefore, in this study, such therapeutic approach was addressed.

Conclusions

Despite the limitations of a laboratory study, it may be drawn that WaveOne Gold and Reciproc Blue systems provided minimal and similar apical transportation. SEM analysis showed defects on the instruments' surface of both systems even before use. However, the number of defects was greater for the WaveOne Gold system, which increased after continuous use. For the Reciproc Blue instrument, the number of defects increased only after the third use. It is licit to state that further studies are needed to better understand the mechanical and metallurgical behaviour of these instrumentation systems during endodontic reintervention.

Clinical Relevance

The research contributes to the evolution of endodontic reintervention protocols.

Conflict of Interest

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

Acknowledgments

None.

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ORIGINAL ARTICLE

Root canal anatomy of mandibular incisors with Vertucci's type III configuration: a micro-CT evaluation

ABSTRACT

Aim: *To evaluate the root canal anatomy of mandibular incisors with Vertucci's type III configuration.*
Methodology: *Forty mandibular incisors were scanned using a micro-CT to measure canal and dentin volume, bifurcation and merging levels, minor and major diameters, long-short diameter ratio, dentin thickness, degree of curvatures and number of foramens.*
Results: *The apical third showed lower volume of canal and dentin. The bifurcation with the formation of buccal and lingual canals presented a mean of 3.75 mm extension. The cement-enamel junction, bifurcation and merging levels showed major diameter ($P < 0.05$). The round shaped canals were found in buccal (67.5%), lingual (85%) and apical sections (55%). In apical section dentin thickness ranged from 1.02 mm to 0.52 mm. No specimen showed root curvature and 82.5% of mandibular incisors presented single apical foramen.*
Conclusion: *The morphologic aspects of root canal bifurcation and merging in mandibular incisors Vertucci's type III do not present a consistent pattern.*

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Introduction

The knowledge of the root canal anatomy configuration is fundamental for the diagnosis and execution of endodontic therapy. As important as knowing the most prevalent anatomy types is the ability to diagnose the possible variations, which can be quite complex, therefore, more difficult to the dentist than the periapical radiography suggests (1). Frequently root canals show a complex anatomic configuration with variations that can be related to the curvature, cross section shape, additional canals, fins, deltas, intercanal connections and accessory canals (2-6). The pattern of a single root canal with a continuous taper, roundness and a single apical foramen is the exception rather than the frequent condition (2, 4). So, the various pathways of canals along the root should be considered and during endodontic preparation the original characteristics of the root canals should be preserved as much as possible (7).

A single root and a single canal have been described as the more usual configuration of mandibular incisors (4-6, 8-11), thus the presence of oval, long oval, and ribbon-shaped canals are very common (2). But the prevalence of two canals should be also considered because canals may divide and rejoin, especially due a bifurcation that occur mainly in the middle third of root. According several authors, the Vertucci type III is the most common anatomical variation found in this type of teeth (4-6, 11-16). In this root canal variation, a single canal splits at the middle root third creating a buccal and a lingual canal. These two canals usually join at the apical third and end in a single foramen (6, 12, 16, 17).

In order achieve the goal of endodontic treatment and to reduce the bacterial load, the morphological characteristics of this dental group should be described in depth. To date, there is limited information about the anatomical parameters of type III mandibular incisors including apical diameters and root thickness. This information can provide anatomical parameters and no micro-CT study showing detailed description of the extension and diameters of bifurcations that may occur at different root levels. Thus, the aim of this study was to evaluate the root canal anatomy of mandibular incisors with Vertucci's type III configuration using the Micro-CT as the analytic tool to measure canal and dentin volume, bifurcation and merging levels, minor and major diameters, long-short diameter ratio, dentin thickness, degree of curvatures and number of foramens.

Methodology

After the approval of this research project by the local ethics committee (protocol 1.051.377) one hundred and eighty extracted human mandibular central and lateral incisors without previous endodontic treatment, root fracture, root resorption, calcification and complete rhizogenesis, extracted for reasons not related to this study from a Brazilian subpopulation were collected in the Human Teeth Bank of the Federal University of Paraná. The teeth were stored in 10% buffered formalin solution for up to a year. The gender and age were unknown. Digital images (Kodak RVG 500, Eastman Kodak, Rochester, NY, USA) were taken in mesio-distal direction and fifty-seven teeth showing a single canal in the coronal third that divides into two canals and merging into a single canal at apical third were selected for this study.

The samples were scanned using a Skyscan 1174 micro-CT (Bruker-microCT, Kontich, Belgium) to confirm the presence of the anatomical configuration of interest. The parameters used were 50kV, 800µA, 0.7 step size rotation and 16.8µm voxel resolution. The digital data were further elaborated by reconstruction software NReconv1.6.4.8 (Bruker). From the reconstruction of the three-dimensional models referring to the root canals of the mandibular incisors, by using CTAn v.1.12 and CTVol v.2.2.1 (Bruker-micro CT), morphologic evaluations were made to confirm the Vertucci's type III configuration (11). After the micro-CT diagnosis, 17 teeth were discarded because not present the anatomical configuration Vertucci's type

III, and the final sample was comprised of 40 mandibular incisors.
The CTAn software was used to evaluate the canal and dentine volume, the data was expressed in mm^3 in four segments (0-1 mm^3, 1-4 mm^3, 4-7 mm^3 e 7-10 mm^3). For the two-dimensional analysis, the CTAn and DataViewer (Bruker-microCT) software's were used to evaluate the root length, root canal bifurcation, merging levels and its extension.
In addition, the minor and major diameters and long-short diameter ratio[2] were measured at the cement-enamel junction level, bifurcation level, middle sections of buccal and lingual canals, merging level and at 1mm below the root apex. The buccal, lingual, mesial and distal dentin thickness in the middle sections of the buccal and lingual canals were also measured. The degree of the root canal curvatures and number of apical foramens were also included in the analysis.

Statistical Analysis
The volumetric and diameter data were analyzed statistically with the D'Agostino and Pearson tests for verification of normality. The comparison between the segments was performed with the Kruskal-Wallis and Dunn's tests for multiple comparisons ($P<0.05$). The statistical analysis was carried out with the GraphPad Prism 8 (La Jolla, CA, U.S).

Results

Considering the volume of root canal and dentin, the apical root segment showed less volume ($P<0.05$), There was no statistically significant difference between the evaluated segments of 4-7mm and 7-10mm just for root canal volume. Table 1 shows the data of root canal and dentin volume in the different thirds.
The root length showed a mean of 12.51mm and the canal bifurcation and merging point varied. Representative images of these variations are shown in Figure 1. The area of the root where a buccal and a lingual canal could be found presented an extension of 3.75mm (±1.61 mm), ranging from 1.16 mm to 6.76 mm. The bifurcation and merging point values taking the apex as the reference were 9.92 mm (±2.03 mm) and 6.08mm (± 1.71 mm), respectively.
The median of the root canal buccolingual diameter at the cementoenamel junction was similar ($P > 0.05$) to the bifurcation level (1.74 mm). This diameter significantly decreases in both buccal and lingual canals to 0.48mm (0.33-0.63) and 0.38 mm (0.32-0.50). These values increased ($P<0.05$) at the merging level (1.61mm) and decrease significantly ($P<0.05$) towards the apex. The average diameter at this level (1 mm) were 0.35mm (0.20–0.71 mm).
The cement-enamel junction showed the largest diameter in mesiodistal direction with 0.44mm and gradually decreased in the following sections until the lower diameter ($P<0.05$) with 0.17 mm at 1 mm below apex section. The major and minor diameters are presented in table 2.
Regarding the transversal cross-section of the canals, the measurement of the major and minor diameter ratios showed long oval-shape at levels that had a single canal, except for the apical millimeter, which had a round shape in 55% of the sample. In

Table 1

Median and 25% and 75% percentile of volume (mm^3) of root canal and dentin volume at different evaluated levels

	0-1 mm	1-4 mm	4-7 mm	7-10 mm
Canal	0.05^{a} (0.03-0.06)	0.26^{b} (0.17-0.37)	0.57^{c} (0.43-0.77)	0.95^{c} (0.66-1.28)
Dentin	1.13^{a} (0.92-1.44)	15.65^{b} (13.17-17.97)	31.84^{c} (27.87-33.52)	43.66^{d} (39.63-47.90)

**Different superscript letters at each line indicate significant difference ($P<0.05$).*

Table 2

Median, 25% and 75% percentiles of buccolingual and mesiodistal diameters (mm) evaluated at cement-enamel junction (CEJ) level, bifurcation, middle sections of vestibular and lingual canals, merging and 1mm below the apical apex

	Buccolingual	Mesiodistal
CEJ	1.54[a] (1.21-1.78)	0.44[a] (0.37-0.58)
Bifurcation	1.74[a] (1.38-2.10)	0.32[ab] (0.27-038)
Mid. Buccal canal	0.48[b] (0.33-0.63)	0.26[bc] (0.21-0.31)
Mid. Lingual canal	0.38[b] (0.32-0.50)	0.26[bc] (0.23-0.31)
Merging	1.61[a] (1.45-1.93)	0.22[c] (0.17-0.29)
1 mm apical	0.35[b] (0.27-0.43)	0.17[d] (0.13-0.21)

Different superscript lowercase letters in each column indicate statistical differences (P<0.05).

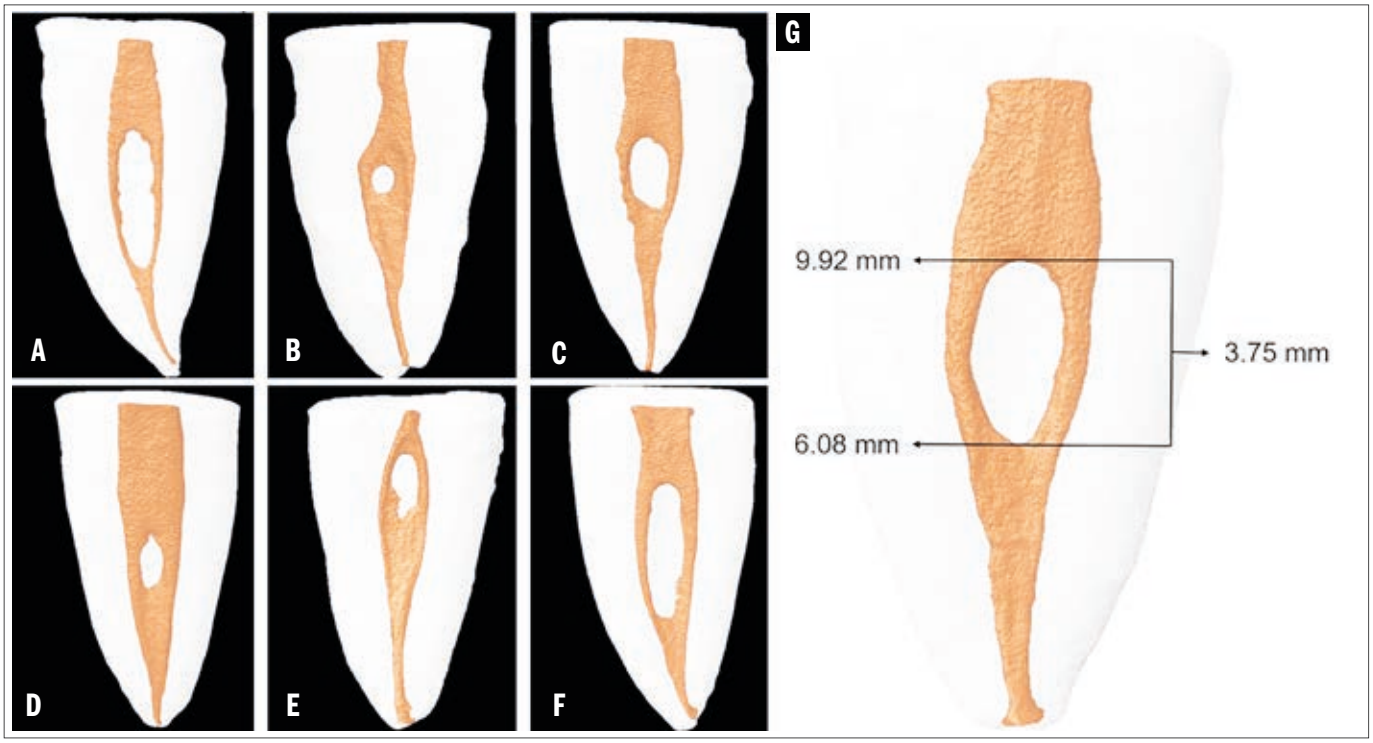

Figure 1
Representative tridimensional reconstructions of mandibular incisors showing different positions and extension of bifurcation and rejoin of Vertucci's type III root canals **(A-F)**. The values represent mean of bifurcation and rejoin from apex and extension of buccal and lingual canals **(G)**.

bifurcated sections, most of the buccal and lingual canals showed round shape in axial sections. The percentage and number of long oval canals at different root canal levels are shown in table 3.

In the middle section of two canals, it was found similar dentin thickness for the buccal and lingual, with mean of 1.85mm and 1.87 mm, respectively, as well as in the mesiodistal direction of the buccal (1.16 mm) and lingual canal (1.12 mm). Considering dentin between canals, it was found thickness of 1.32 mm. In the apical millimeter, the mean lingual dentin was higher than the buccal and mesiodistal dentin thickness, 1.02 mm, 0.70 mm, and 0.52 mm, respectively (Figure 2).

The roots showed a mean curvature of 8.85 degrees (±3.70) in the buccolingual direction and 11.53 degrees (±4.13) in the mesiodistal direction. The curvature values in degrees are shown in Figure 3. Regard-

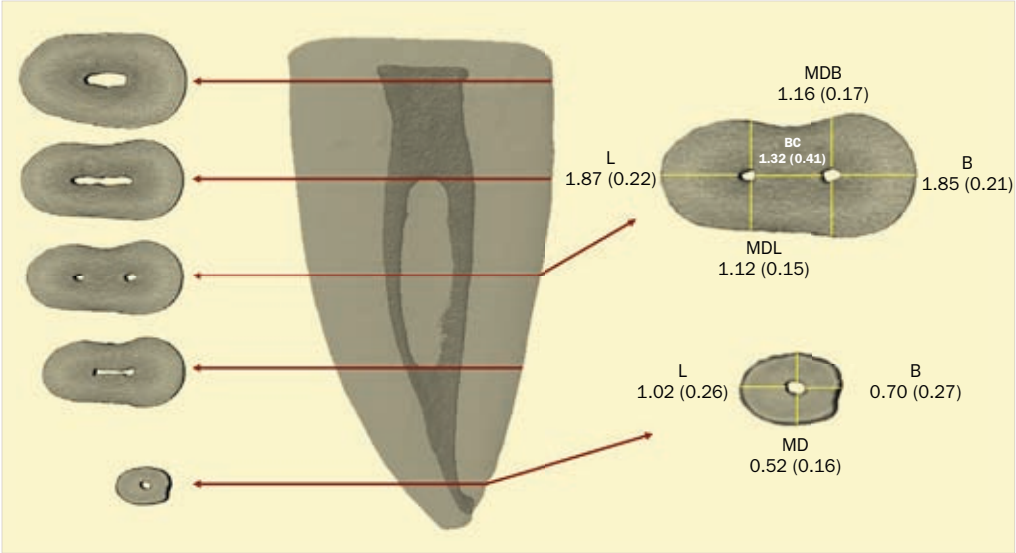

Figure 2
Tridimensional reconstruction of representative sample showing axial cross sections of bifurcation, vestibular and lingual canals, merging and 1mm below the apical apex. The mean and standard deviation of buccal, lingual, mesial and distal dentin thickness in the middle sections of the buccal and lingual canals and at the apical apex section are also shown.

Table 3

Percentage and number (n) of long oval canals evaluated at cement-enamel junction (CEJ) level, bifurcation, middle sections of vestibular and lingual canals, merging and 1 mm below the apical apex

Level	0-2	>2-4	>4-6	>6-8	>8-10	>10	Total long oval canals
CEJ	12.5 (5)	60 (24)	25 (10)	2.5 (1)	0 (0)	0 (0)	87.5 (35)
Bifurcation	0 (0)	22.5 (9)	32.5 (13)	35 (14)	7.5 (3)	2.5 (1)	100 (40)
Mid. Buccal canal	67.5 (27)	30 (12)	2.5 (1)	0 (0)	0 (0)	0 (0)	32.5 (13)
Mid. Lingual canal	85 (34)	15 (6)	0 (0)	0 (0)	0 (0)	0 (0)	15 (6)
Merging	2.5 (1)	2.5 (1)	15 (6)	40 (16)	22.5 (9)	17.5 (7)	97.5 (39)
1 mm apical	55 (22)	35 (14)	5 (2)	2.5 (1)	2.5 (1)	0 (0)	45 (18)

ing the number of foramina, 82.5% of the specimens (n=33) showed only one major foramen, but, in 10% of the samples (n=4) 2 apical foramina were found, in 5% (n=2) 3 apical foramina and 2.5% (n=1) 4 apical foramina.

Discussion

The type III configuration in mandibular incisors has been reported as the second most prevalent type, its prevalence may be influenced by ethnicity. Martins et al. (10) observed the Vertucci's type III configuration in 5.7% in the Brazil population, respectively, whereas the Syria ethnicity group presented 48.7% and Nigeria ethnicity group presented only a prevalence of 2.3% and the overall prevalence was 21.9% for mandibular central incisors and 26.0% for lateral incisors Shemesh et al. (11) found a higher prevalence of 33.7% and 31.9 in the Israeli population. In this study, mandibular incisors were collected from the Brazilian population, in which the type III variation is not uncommon and

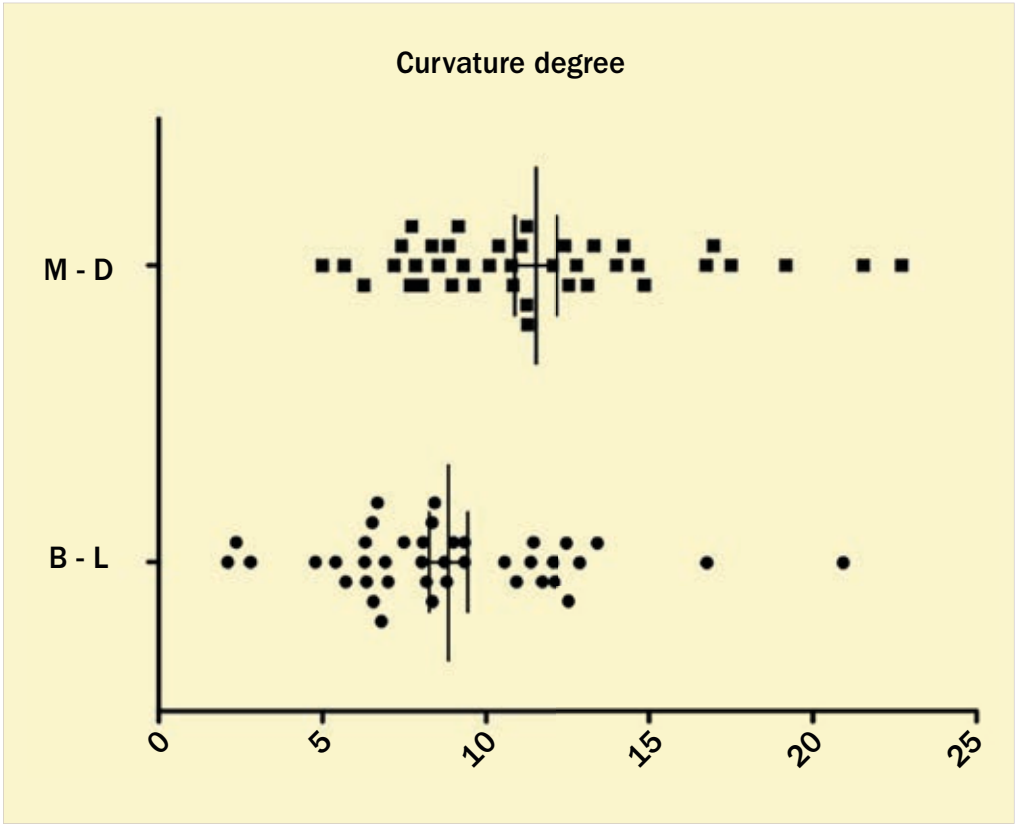

Figure 3
The degree of root canal curvatures in the mesiodistal (M-D) and buccolingual (B-L).

can be present ranged from 5,7% to 28% (4, 6, 10, 16).

Previous studies using different methods observed that the internal root canal configuration of central and lateral mandibular incisors was similar (4, 9-12, 18), and according to Wu et al. (19), most of subjects with complicated root canals in permanent mandibular central incisors had bilaterally complicated root canal configurations. Root canals of mandibular incisors are similar bilaterally (15, 16). So, in this study, there was no distinction between them and the sample selection.

Vertucci type III configuration (12) is characterized by one canal leaving from the pulp chamber, which is divided into two within the root, and then merged to exit as one canal, however, this configuration does not always follow the same pattern, a great variability of the location and extension of the bifurcations and rejoins were observed in the three-dimensional images of the samples in this study. Whereas the mandibular incisors have an average length of around 21 mm, measured from the apex to the incisal edge (4), and root length of mean 12.51 mm as found in this study, we observed that, in the most samples, the canal bifurcation started in the cervical third and rejoin in the middle third of the root, showing buccal and lingual canals located mainly in the middle third of the root, in disagreement with results of Shemesh et al. (11), that found that both in central and lateral mandibular incisors the separation into two canals was in the middle third of the root. However, it is important to point that the authors considered a mean among II, III, IV and V types. Martins et al. (20) reported that bifurcation may also to occur at any root level. The great variation in the location of the bifurcation represents an additional challenge for accessing the lingual canal during endodontic treatment, which may be the greatest cause of failure in endodontic treatment in this dental group.

In this study, the septum formed between bifurcation and rejoin showed a mean of

3.75 mm, with minimum of 1.16 mm and maximum of 6.76 mm, but according to Shemesh et al. (11) in one-third of the cases, the septum was smaller than 1mm. It is important to say that in our findings there was variation in the level and extension of the bifurcation, which may start in the cervical or middle third and rejoin in the cervical, middle or apical third of the root canal. The knowledge of canals bifurcation and the location of the separation is fundamental for endodontic outcome, because missed and untreated canals were associated with the presence of apical periodontitis (21). Evaluating the anatomical root structures is essential before starting an endodontic treatment, the clinician must perform radiographs with variations in the horizontal angle, and when in doubt regarding the morphology of the root canal, more accurate imaging methods, such as Cone-beam computed tomography (CBCT), which provides a more accurate and detailed investigation of root anatomy (22), can be requested. Sahoo et al. reported endodontic treatment in a Vertucci type III root canal, in which it was only possible to diagnose this anatomy after performing a CBCT scan (23).

Our results showed a smaller volume of canal and dentin in the apical root third, which was increased in the cervical direction, but we cannot compare these data, because there is few available information about the root canal volume in mandibular incisors. One study evaluated the total volume of root canal, however, it has made no distinction to configuration type of the canal (4), whereas, in the only study that evaluated the volume of type III root canals, this was done only in the apical third 6 and presented higher volume than we found in our study. A small root canal volume consequently allows a small volume of irrigant solution, which may compromise disinfection and favor hard tissue accumulation during the shaping procedures, so the continuous refreshment of solution is necessary because greatly increases the effectiveness of irrigation (24).

The diameter of the root canal is a variable that influence the shaping and cleaning procedures. In this study, it was observed that the mesiodistal diameter increases progressively from the 1mm apical section (0.17 mm) to the CEJ (0.44 mm). However, the buccolingual diameter must be highlighted because it presented sudden variations along the canal, a high diameter (1.54 mm) was found in the CEJ section, similar the bifurcation section (1.74 mm), but significantly reduces in the buccal (0.48 mm) and lingual (0.38 mm) canals, then it significantly increases in rejoin section (1.61 mm) and again significantly decreases at 1mm apical section (0.35 mm). This variation in diameters will influence the selection of instruments to perform endodontic treatment, which require instruments with a lower taper. A smaller buccolingual diameter observed in the CEJ level, than in the section of root canal bifurcation, confirm the presence of a prominent bulge of dentin in the CEJ area, which makes the detection difficult and debridement of a lingual canal. The ideal coronary access is not obtained with a lingual approach, but when used the access from the lingual, it should be moved as far toward the incisal as possible (25). However, one should always consider the presence of a bifurcated canal and, clinically, perform a modified coronal access, extending the access cavity lingually, in an oval shape, to facilitate the location of the lingual canal.

Wu et al. (2) defined as long oval canal when the cross-sectional ratio of long to short canal diameter was 2, following this proposal, in this study it was found predominantly long oval canals in the CEJ level (87.5%) as well as in the bifurcation (100%) and rejoin sections (97.5%), however between these levels the buccal and lingual showed round shape in 67.5% and 85%, respectively. Previous studies showed at 1mm short of the apical foramen the minor diameter raging from 0.21 mm to 0.25 mm and major diameter raging from 0.37 mm to 0.49 mm for general mandibular incisors (2, 4, 12) and 0.22 mm and 0.41 mm, respectively, for type III anatomy (6). These data were similar those found in our study (0.17 mm – 0.35 mm), but the high major diameter observed was 0.71 mm. So, it should be considered the prev-

alence of higher apical diameters than 0.35 mm at the 1mm apical level, where canal shaping is usually ended. Therefore, an instrument with an apical diameter of at least 0.35 mm is required to touch all the root canal walls in the apical region. Another important point to consider is that 45% of the samples presented long-oval shape, corroborating with Milanezi et al. (6) that found 37.5% of oval-shaped canals in the 1mm apical level of type III anatomy and it was more prevalent in comparison to type I with 16.7%. This data may explain the difference between our results and Wu et al. (2) study that found only 10% of oval canals in this same root position.

Mechanical preparation of long oval-shaped canals could represent a challenge for clinicians. Recent studies have shown that different contemporary endodontic instrument systems were not able to provide optimal shaping ability in both oval-shaped canals (26) and long oval-shaped canals (27) of mandibular incisors, these studies used instruments with different tapers and tip size #25 and #30, respectively. In this study, the type III canals showed a variation in diameter and cross section along the root, which can make difficult the properly shaping and cleaning.

The increase of apical enlargement promotes important outcomes such as significantly reduction in percentage of unprepared canal areas (28) and less hard tissue debris accumulation (29) due the improvement of the flushing action of irrigants by deeper penetration in the root canal system. Furthermore, in infected root canals the enlargement of the apical preparation promotes greater intracanal bacterial reduction (30). However, during treatment, the clinician must take into account that, the expectation of using instruments with large tip and taper to shape and touch all canals walls and providing a round preparation could lead to accidents such as stripping or perforation due the flat characteristic of the root. The bifurcation section may be a potential risk area because the average of dentin thickness on both the mesial and distal walls shows 1.16 mm for the buccal canal and 1.12 mm for the lingual canal. Furthermore, even after apical enlargement canals with anatomical complexity may not be completely free from packed hard tissue debris (28, 29) and bacterial cells (30).

Cleanliness of untouched canal areas by instruments depends on irrigants action (27), so the constant refreshment and agitation of the irrigant with complementary methods such as passive ultrasonic irrigation and mechanical irrigant agitation devices, increases the effectiveness of the solutions and improves canal debridement (31, 32). Bao et al. (32) showed that the XP-endo Finisher allowed to remove biofilm from hard-to-reach areas in the root canal system. Ultrasonic tips like Flatsonic and Clearsonic as an auxiliary method for the rotary or reciprocate instrumentation of oval-shaped canals increases canal volume and surface, reducing the non-instrumented areas of the root canal system (33).

The teeth presented a low degree of curvature, both in the buccolingual and mesiodistal direction, only 1.2% of the sample presented curvature greater than 20 degrees. Despite we found 82.5% of sample a single apical foramina and a cone beam computed tomography study showed 100% of in mandibular incisors (21), it was observed in this study one tooth with an apical delta (four foramina), also reported in a previous study (4), so the presence of multiple foramina should also be considered in mandibular incisors with type III canal configuration.

With advances in digital imaging, instrumentation and anatomical studies, the endodontic treatment of root canals with anatomical complexities has become more predictable. In the case of lower incisors, the clinician must be aware of possible anatomical variations, always take radiographs with variation in the horizontal angle, extend the access to the cavity in the lingual direction and probe an additional canal, and also consider CBCT, which is a useful technique for endodontic diagnosis and treatment.

The limitations of this study limitations stem from both the sample size and the narrow focus on specific categories of teeth. However, it's important to view this as an initial study that lays out the criteria

for future research targeting the endodontic management of root canal anatomy of Vertucci's type III mandibular incisors and the morphological variations that may occur. Future studies will be necessary to evaluate the shaping of these canals in order to suggest the appropriate tip and taper of the instrument for this anatomical condition.

Conclusion

The morphologic aspects of root canal bifurcation and rejoin in mandibular incisors Vertucci's type III do not present a consistent pattern. In this anatomical configuration, oscillation occurs in the largest diameter and cross-sectional shape along the root canal.

Clinical relevance

The Vertucci type III is the most common anatomical variation found in mandibular incisors.

Conflict of interest

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

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CASE SERIES

Innovative Approaches for Treating External Cervical Resorption: a Comprehensive Case Series

ABSTRACT

Aim: *The aim of this case series was to provide information on the clinical management of different types of external cervical resorption (ECR) lesions. This case report has been written according to Preferred Reporting Items for Case reports in Endodontics (PRICE) 2020 guidelines*

Summary*: ECR is a condition that is difficult to diagnose and manage and can lead to tooth loss if not treated properly and on time. This series of three case reports outlines effective methods for planning and managing teeth with ECR in a minimal invasive and effective way .*

Key learning points:

- *The decision to maintain a resorbed tooth should be made on a case-by-case basis, taking into consideration various factors, such as the extent and location of the resorption, the patient's overall dental health, and the treatment options available.*
- *Single visit handling in such cases is predictable and effective, granted the experience and the of the dedicated equipment.*
- *In cervical resorption lesions vitality can be maintained when diagnosis is obtained on early stages.*

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Introduction

Root resorption refers to the loss of hard dental tissues (cementum, dentin, or enamel) owing to the activity of odontoclasts (1). While it is a natural and desirable process in primary teeth, where it facilitates the shedding of teeth and the emergence of permanent teeth (known as physiological root resorption), it is undesirable in adult teeth, as it can lead to irreversible damage which requires treatment or extraction.

Resorptions can be classified into external and internal root resorptions, based on their location on the root surface. External root resorption is further categorised into surface, inflammatory, cervical, replacement, and transient apical resorption, as defined by Patel and Pitt Ford (1, 2) and Patel and Saberi (3). External cervical resorption (ECR) typically occurs in the cervical aspect of teeth and is caused by damage or deficiency of the periodontal ligament (PDL) and subepithelial cementum, according to Andreasen and Andreasen (4). ECR is a dynamic process that affects periodontal, dental, and pulpal tissues in later stages (5, 6) and has gained more attention in the last two decades owing to improved detection using cone-beam computed tomography (CBCT) (1, 7, 8) and advanced assessment techniques such as micro-computed tomograophy (CT) and histopathology (6, 9, 10).

ECR can be challenging to diagnose and manage, and early detection is important to prevent further tooth damage. The most frequent diagnostic method is random radiographic control; otherwise, ECR is detected when it is severely spread, being either symptomatic with toothache when the pulp is involved or with the presence of pink discoloration on the cervical part of the tooth (pink spot) (11,12).

The treatment for ECR varies from external or internal repair of the resorbed tissue to root canal treatment when the pulp is involved and to intentional reimplantation, observation, or extraction based on symptoms, extension, and early or late detection (11). Despite all these treatment option it is importan for the clinician to understand the rational of maintinig or not a resorbed tooth. Obviously this choice depends on the conditions (positioning and extension of the resorptions), the function of the compromised tooth in the mouth, and certently on the genereal health of the oral cavity of the patient in treatment. The survival rate of ECR repaired teeth appears to be less favorable than of teeth under periodic observation, fact which implies that many times resorbed teeth are heavily compromised to be repaired or maintained (13). Unfortunately when symptoms are present, observationon is not an option. The aim of this case series was to provide information on the clinical management of different types of ECR lesions based mainly on the cost-effectiveness of the treatment for both the clinician and also the patient. This case series has been written according to Preferred Reporting Items for Case reports in Endodontics (PRICE) 2020 guidelines (14) (Fig. 1-3).

Report

Case 1

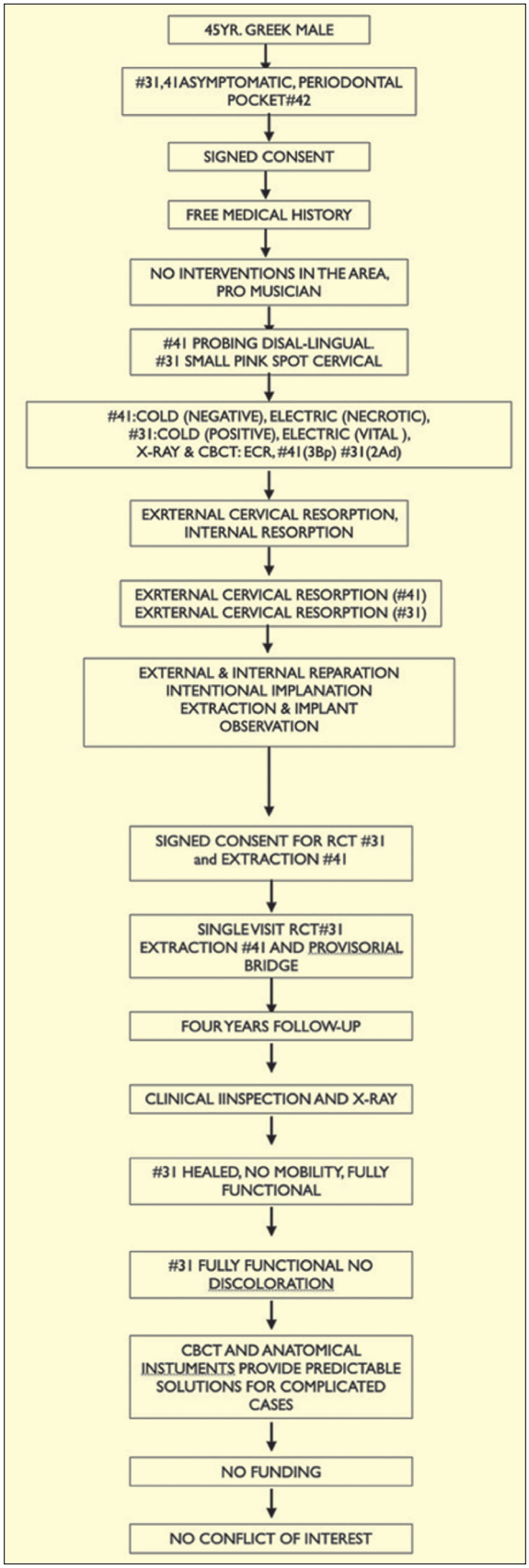
A 45-year-old man, greek with no medical history, was referred for endodontic evaluation of tooth #42 suffeing of periodontal problems with deep pockets (12 mm) and mobility 1. Radiographic investigation revealed resorption of teeth #41 and #31 (Fig. 4a). The patient did not report any symptoms in the area, and the only complaint was the mobility of #42. No previous intervenmtions were mentioned by the patient in the aera.

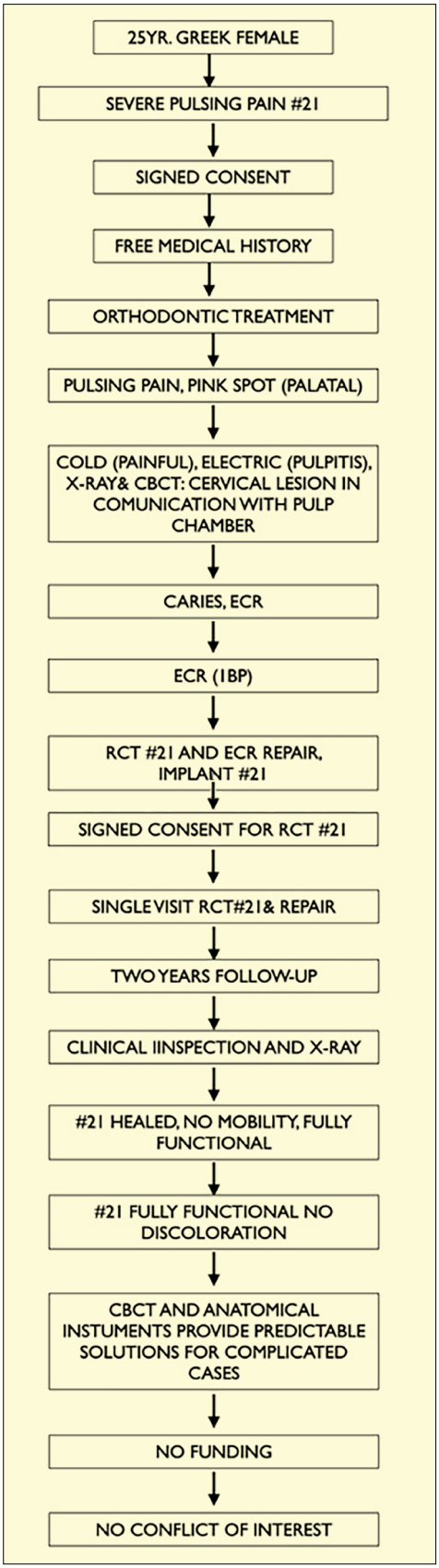
In the clinical investigation (cold and electric), #41 showed negative vitality, and #31 showed positive results in all vitality tests, with no evident pain symptoms.

After informing the patient and obtaining their consent, CBCT of the area was performed to thoroughly evaluate the resorbed elements and determine the most effective treatment plan. Three-dimensional imaging revealed massive resorption of tooth #41 in the lingual aspect of the root, extending to the medial and apical third of the root, communicating with periodontal tissues to the greater extent of its surface

Figure 1
Preferred Reporting Items for Case reports in Endodontics flow-chart for Case 1.

Figure 2
Preferred Reporting Items for Case reports in Endodontics flow-chart for Case 2.





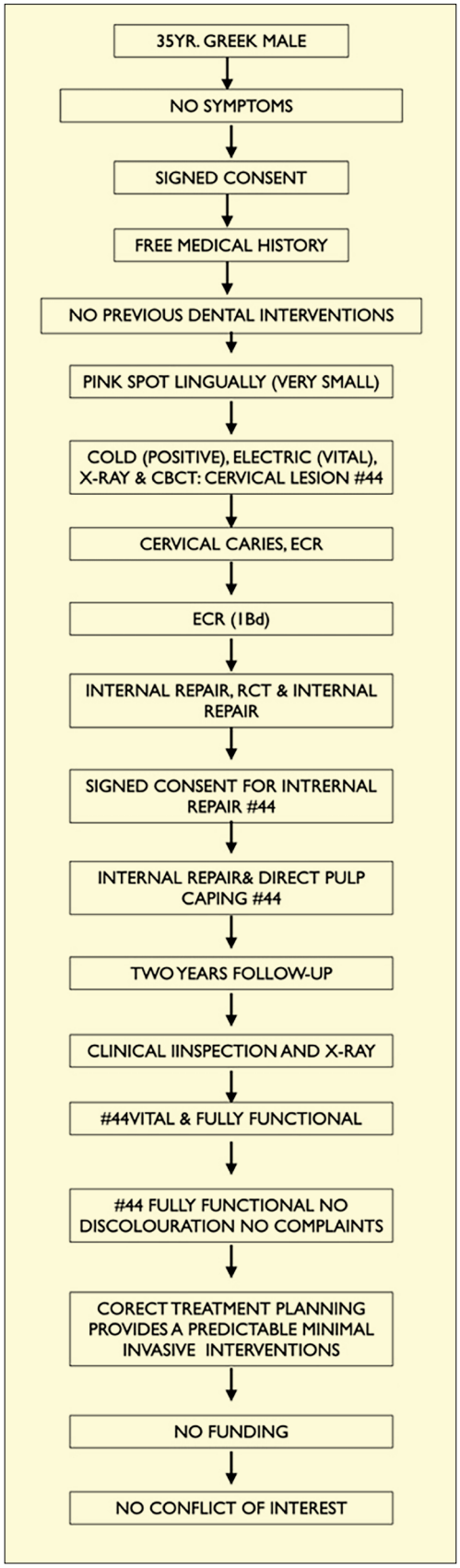


Figure 3
Preferred Reporting Items for Case reports in Endodontics flowchart for Case 3.

(Fig. 5a). A more localised and centrally positioned resorption area was observed in tooth #31, and a small communication was observed in the mesial part of the medial third of the tooth (Fig. 5b). Based on both clinical and radiological findings, the teeth were diagnosed with ECR. According to the most accurate classification which describes the position (1:CEJ- 4:apical third), the extension (A<90o-D>270o) and the depth of the resorption, (d:dentine, p:pulpalinvolvement), tooth #41 presented a 3Bp resorption and #31a 2Ad lesions (15).
The patient was informed about different treatment options. Importantly, the patient was a professional trombone player, which may have caused the ECR lesion in the first place.
The internal and external repair of tooth #41 was aborted because of the risk of periodontal complications. No intentional reimplantation was considered because of the patient's occupation and the need for more secure treatment.
The final treatment plan was extraction of tooth #41 and endodontic treatment of tooth #31 (internal repair). The extracted #41 would initially be replaced with a bonded bridge (#42–31) until further periodontal evaluation and implant placement at a later moment. Patient was informed about treatment options and the final treatment plan, which he agreed to proceed. At the same appointment, we proceeded with the endodontic treatment and repair of tooth #31.
Local anaesthesia and rubber dam isolation were performed before access cavity preparation with a long round diamond bur 0.012 tip (D&Z DIAMANT, Kalletal, Germany) under an operating microscope Ompi Pico (Zeiss, Oberkochen, Germany). Using k-file #10 (FKG Dentaire, La Chaux de Fotns, Switzerland), scouting was performed, and patency was obtained. The working length was measured electronically (Morita Root ZX Mini, J. Morita Corp, Tokyo, Japan). Chemomechanical preparation was completed using an anatomical file XP Endo Shaper (FKG Dentaire) at 1,000 rpm and 1N/cm. During preparation, 15 mL of 5.25% NaOCl was used for irri-

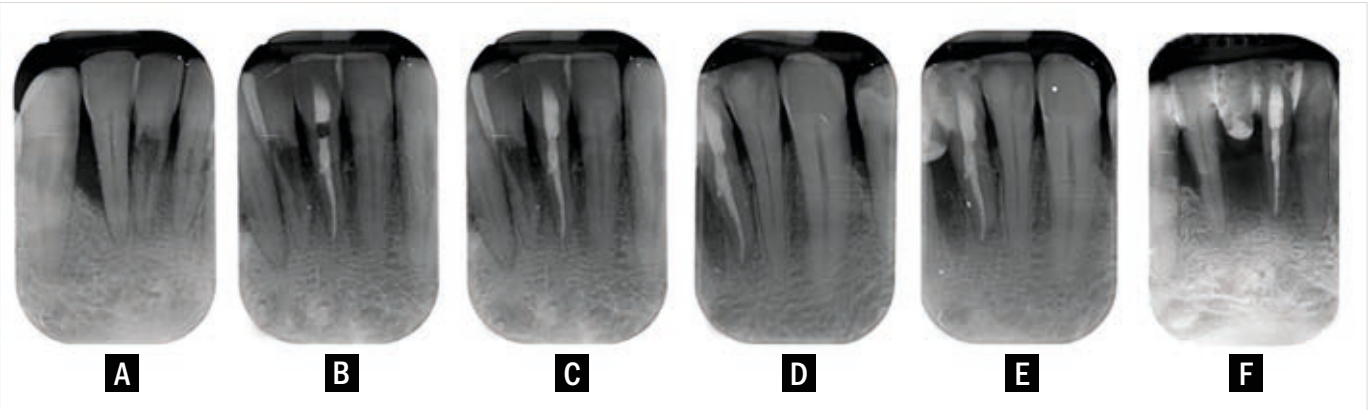
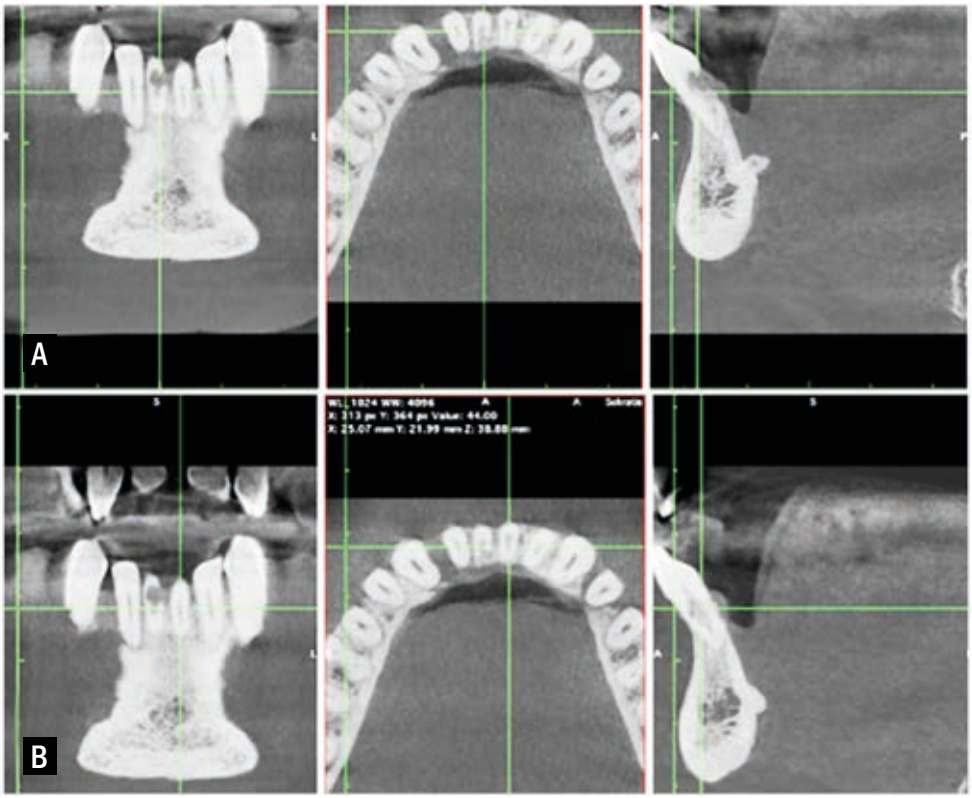


Figure 4
Periapical radiographs of Case 1: **A)** initially, **B)** after RCT #31, **C)** after restoration #31, **D)** after extraction #41 and bonded bridge placement, **E)** at 6-month follow-up.

gation with an IRRIFlEX needle (Produis Dentaires SA, Vevey, Switzerland).
After preparation, the root canal space was debrided using an XP Endo Finisher (FKG Dentaire) at 1000 rpm and 1 N/cm. During this procedure, 10 mL of 5.25% NaOCl and 5 mL of 17% ethylenediaminetetraacetic acid were used. The debridement protocol was performed twice, each for 30 s. First, the root canals were irrigated with activated NaOCl, followed by irrigation with activated ethylenediaminetetraacetic acid for 30 s. After debridement, NaOCl was left in the root canal space without agitation for 3 min, followed by rinsing with 10 mL of saline solution. Consequently, a 35.04 TotalFill BC Point gutta-percha cone (FKG Dentaire) was fitted to the canal. The canal space was then dried using sterile TotalFill BC Point paper cones (FKG Dentaire). After drying, the bioceramic TotalFil BC Sealer (FKG Dentaire) was placed in the root

Figure 5
Cone-beam computed tomography images of Case 1.



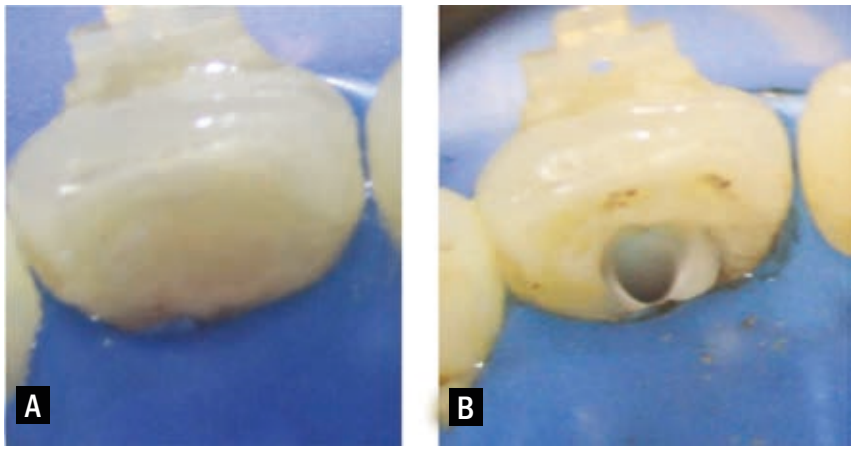


Figure 6
Clinical images of Case 2: **A)** isolation, pink spot on palatal, **B)** after cleaning the ECR.

canal space using an application tip. The gutta-percha cone was then placed in the canal and cut 3 mm from the orifice, and the rest of the canal was filled with thermoplastic gutta-percha and compacted vertically. After terminating the root canal treatment (Fig. 4b,c), the final composite restoration was performed, and the patient was referred to his general practitioner for the extraction of #41 and temporary bridge placement. Periodontal sessions were arranged to prepare the implant site and the desiesed area.
Follow-up was performed after 6 months and 4 years (Fig. 4d, e, f), and the teeth appeared healthy (clinically and radiographically). At the later follow-up the bonded bridge was still in place and no implant was placed yet. Since all was functional (esthetics and fonetics) the patients decided to maintain this setting for longer time. Meanwhile bone healing proceded regularly. The patient was happy about the overall treatment, teeth were fully functional and permiteed the patient to continue his profession as a trombone performer.

Case 2
A young greek woman (25 years old) was referred for evaluation of tooth #21 because of severe pulpitis. Clinically, the tooth was free of caries, and only a small pinkish spot was evident in the palatal part of the crown at the gingival level with deeper probing (6 mm) (Fig. 6a). The patient was in the final step of orthodontic therapy. Radiographic evaluation revealed a cervical lesion communicating with the root canal (Fig. 7a). Positive vitality test results were observed with pain on cold and electrical stimulation. The patient was informed of the possibility of ECR, and CBCT was performed for a more precise evaluation and treatment planning.
CBCT revealed a cervical lesion in the apical and medial parts of the crown, extending into the dentin and pulp chambers. Vertically, the lesion did not extend below the bone (supracrestal). Communication with the gingiva was evident in the palatal aspect of the crown (1 Bp) (15) (Fig. 8a, b, c).
Owing to pulpitis symptoms, endodontic treatment and internal repair of the ECR

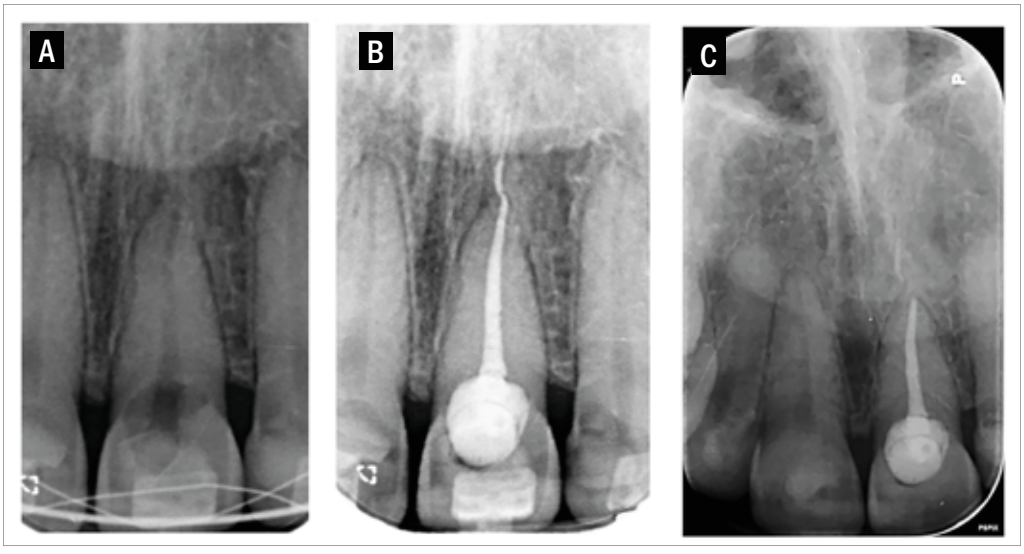


Figure 7
Periapical radiographs of Case 2.

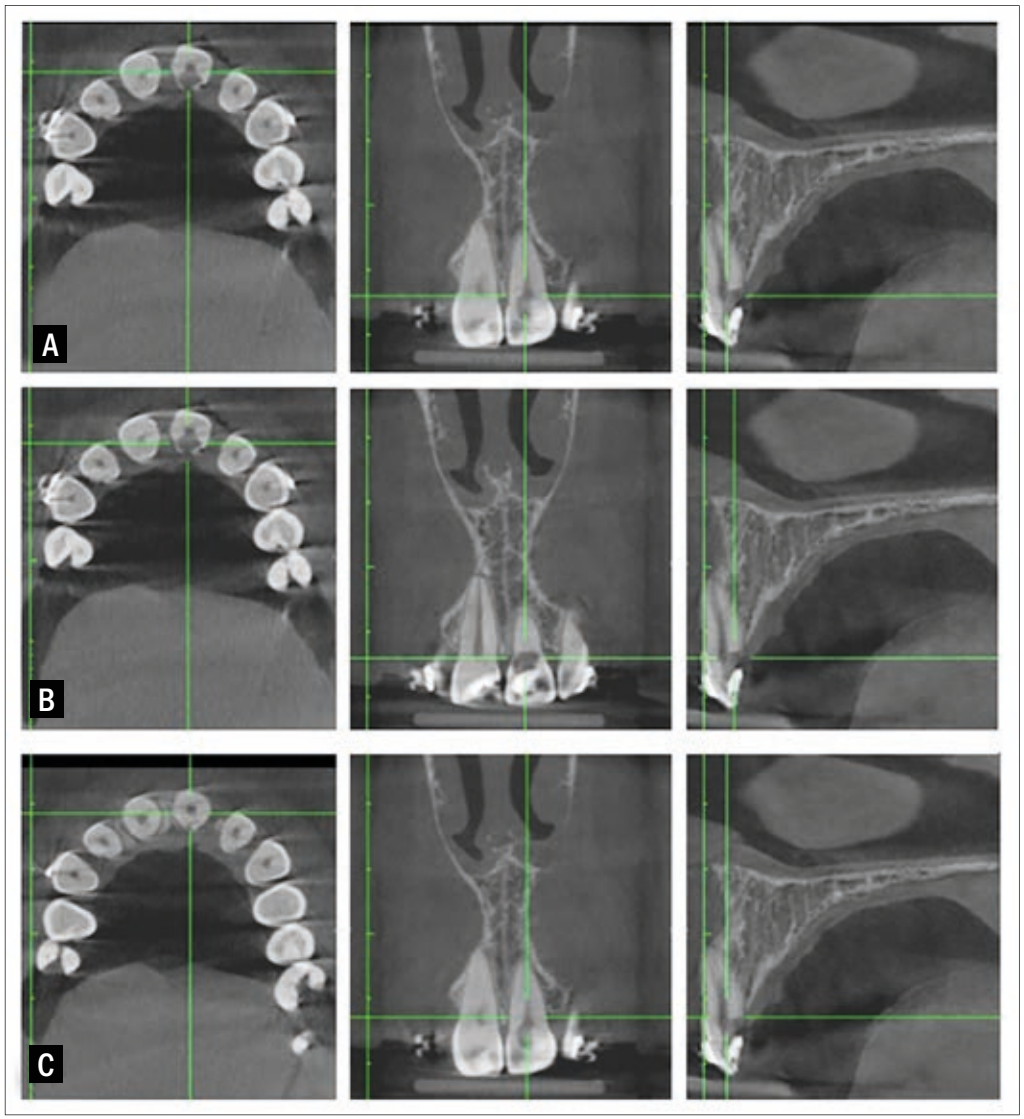


Figure 8
Cone-beam computed tomography images of Case 2.

were decided; otherwise, internal repair would have been performed while maintaining vitality under observation. The patient was informed about treatment possibilities and options and agreed to undergo the root canal treatment and repair of the resorption area.

For better isolation, removing the wire from the brackets before beginning endodontic treatment is recommended. The tooth was anaesthetised and isolated with multiple isolations to avoid interference between the clam and the ECR. To obtain concrete isolation in the palatal part, a double-knotted ligature was placed in tooth #21 to push and maintain the dental dam apically (Fig. 6a). Access was gained through a long round diamond bur 0.016 tip (D&Z DIAMANT) under an operatory microscope, and the resorption site was thoroughly cleaned using a bur and 90% aqueous trichloroacetic acid placed on a microbrush.

After cleaning the resorption, the root canal was accessed with K-file #10, and patency was obtained. The working length was measured electronically using an apex locator (Morita Root ZX Mini, J. Morita Corp). Chemical preparation, debridement, and obturation were performed following the protocol described for Case 1 (Fig. 6b). In this case, a gutta-percha cone 45 was fitted and, the single-cone technique with a bioceramic sealer was performed. During

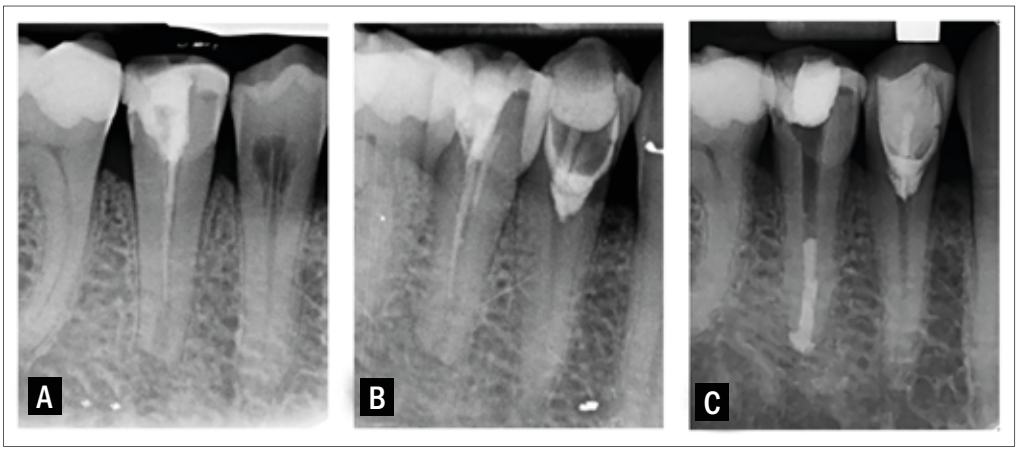


Figure 9
Periapical radiographs of Case 3.

the same session, while maintaining the same isolation, the cleaned ECR site was repaired using direct composite restoration (Fig. 7b).
Follow-up was performed after 2 years. The patient then underwent orthodontic treatment. No clinical or radiographic findings (Fig. 7c) were observed, and the tooth became fully functional and aesthetically stable without the need for bleaching.

Case 3
A young greek male (35 years old) was referred by his general physician after noticing a strange finding using periapical radiography. A lesion was observed in the cervical area of tooth #44 using characteristic ECR imaging. CBCT revealed a lesion in the crown of #44, extending from the cervical to the medial area of the crown (supracrestal). Small communication was observed lingually at the cemento-enamel junction level (1 Bd) (15). Clinically, there was no evidence of communication or caries. A small probing (5 mm deep) was found at the communication site. Vitality was positive in both cold and electric tests. The patient had no relevant complaints.
After informing the patient about the condition of the tooth and the possible implications if not treated, the patient agreed to proceed with internal reparation of the ECR aiming to avoid further demineralisation and maintain the vitality of the #44 as long as possible.
After anaesthesia, multiple isolations were performed, and the dental dam was positioned apically with a double-knotted ligature. Access was obtained using a long round diamond bur 0.012 tip (D&Z DIAMANT) under an operating microscope. The ECR was cleaned carefully using a long

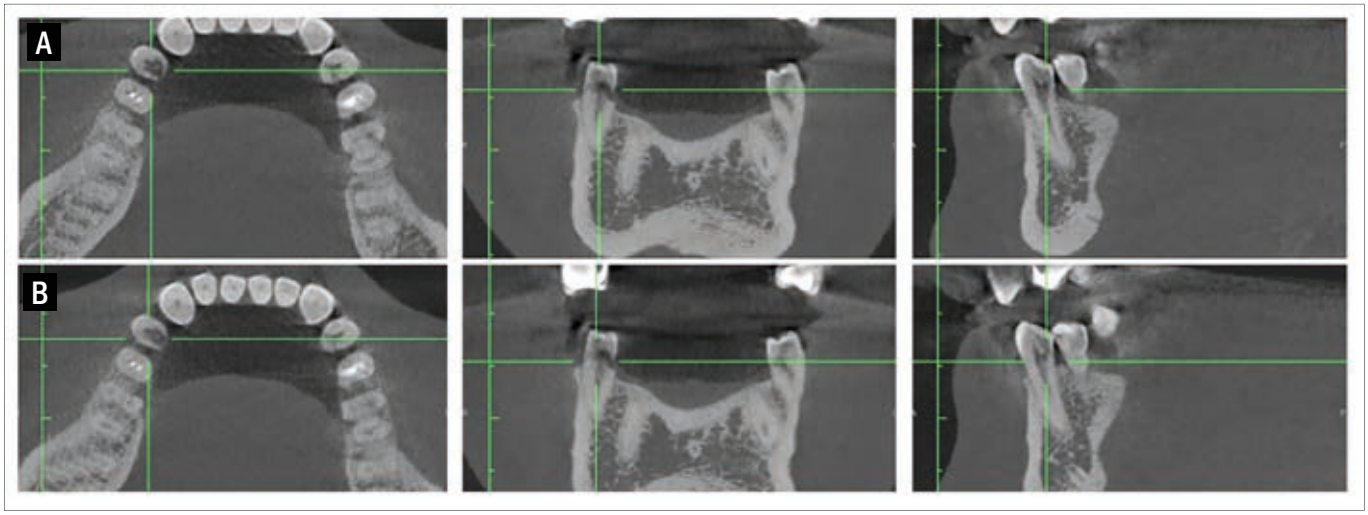


Figure 10
Cone-beam computed tomography images of Case 3.

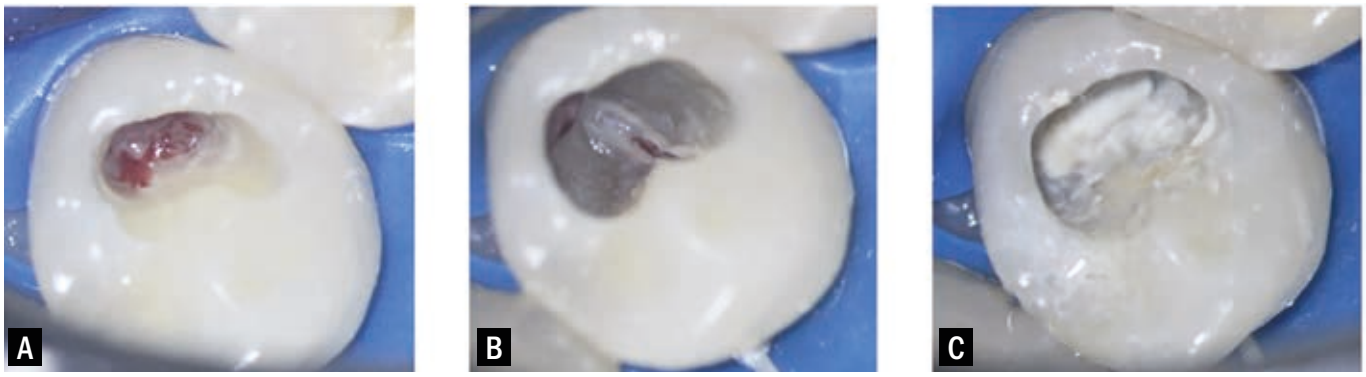


Figure 11
Clinical images of Case 3.

round bur; using 90% aqueous trichloroacetic acid placed on a microbrush, the bleeding sites around the pulp chamber were carefully scraped. During the cleaning of the resorption, communication with the pulp chamber was created owing to the extension of the ECR. The minor bleeding from the pulp was controlled using sterile cotton pellets soaked in NaOCl (5.25%). After cleaning, the cavity was washed with saline solution, and pulp caping was performed using a bioceramic premixed putty Total Fill Putty Fast Set (FKG Dentaire). After 15 min, to avoid excessive contact with the pulp-capping site, a very thin and small layer of flowable composite material was placed and polymerised above the bioceramic capping. Subsequently, bonding was performed to the entire cavity using a self-etching primer and bonding Optibond XTR (Kerr Dental, Brea, Canada), and a thin layer of flowable material (Revolution, Kerr Dental) was placed and polymerised. Finally, the composite restoration was positioned in the cavity.
Follow-up was performed after 2 years. Vitality was positive, and the tooth was fully functional. At the follow-up, the patient mentioned difficulty while chewing with tooth #45, which seemed symptomatic, and root canal retreatment had to be performed. In a clinical follow-up to the second treatment the patient was fully satisfied about the functionatily of the treated territory.

Discussion

ECR is a pathological process that can lead to significant loss of tooth structure and result in tooth loss if left untreated or not diagnosed during the early stages. The decision to maintain a resorbed tooth should be made on a case-by-case basis, taking into consideration various factors, such as the extent and location of the resorption, patient's overall dental health, and treatment options available. In the three cases described above, the majority of treatment options for ECR aimed to maintain resorbed tooth function (11). ECR treatment options vary from external and internal repair to intentional reimplantation, extraction, periodic follow-up, or also regenerative endodontic treatment (RET) (16) depending on the severity of the case and the extent of resorption of the dental tissue and crestal bone. As reported previously, in heavily compromised teeth (class 3 or 4 resorption), the outcome of external repair is poor, making this treatment option less favourable in such cases (11).
Intentional reimplantation is reported to be a cost-effective and predictable treatment, especially for ECR lesions (17,18); however, it is usually preformed in cases with minor resorption in dentin and difficulty in restoration (17,19). Periodic follow-up is always an option for heavily compromised teeth with no symptoms and no treatment possibilities, provided that no further problems occur owing to the compromised tooth. In the first case, even if tooth #41 was asymptomatic, there was severe periodontal lesion involvement, and further delay would have led to problems in future restoration of the area. In this case, extraction and implant replacement appear to be the most cost-effective and long-lasting choices (20). As for the regenerative endo-

dontic treatment (RET) as a treatment option, even though it would be a promising treatment option, there is still no solid evidence about positive outcomes of such treatment (16).
Successful clinical outcomes of resorption cases depend largely on early detection and accurate differential diagnosis. It is essential to differentiate between internal and external tooth resorption, which can be achieved through radiographic examination and an understanding of the internal root anatomy. The advent of diagnostic aids such as magnification and CBCT has further improved the accuracy of diagnosis, enabling predictable treatment and enhancing the prognosis. In addition to the fact that CBCT is fully recommended in such cases by the European Society of Endodontology (20) and Joint American Association of Endodontists/ American Academy of Oral and Maxillofacial Radiology Position on Cone Beam Computed Tomography (21), CBCT can be used to identify the location and extent of resorption more accurately and in detail, enabling clinicians to plan appropriate treatment strategies. With the help of advanced image-processing techniques, CBCT images can be enhanced to improve the visualisation and detection of resorption areas. This has significant implications for the management of patients with root resorption because early detection can lead to improved outcomes and prognosis.
All presented cases were treated in a single visit. Single-visit endodontic management is recommended in cases in which recontamination of root canals can be prevented (11). When ECR is extended and communication with the root canal space occurs during treatment, an interappointment is recommended to obtain the correct coagulation through calcium hydroxide (22); nevertheless, with the use of anatomical instruments, it is possible to clean the root canal space thoroughly and obtain a perfectly dry root canal space in a single visit (23). The use of bioactive filling materials for the root canal space and as dentine substitutes is likely to prevent the osteoclastic activity of any ECR cell possibly remaining at the site during the high phase and thus prevent resorption (24).

It is known that the significnance of case reports and cases series is lower in comparison to clinical trials and RCTs, but ECR is a rare and difficult to treat condidion and data about treatment and survival of resorbed teeth are not really available. Even though there are articles describing management options of different conditions (10, 20), most references about optimal treatment of ECR is bases on case reports. (24-28).

Conclusion

ECR is a severe condition in affected teeth that can lead to tooth loss if not diagnosed on time. Despite the limited number of cases reported, this article underlines the importance of early diagnosis, treatment planning, and appropriate material use for maintaining the function of resorbed teeth in the mouth. Further clinical studies are needed in the future, for a better appreciation of ECR and the treatment options.

Clinical Relevance

Cervical resorption is an invasive and silent wear to sound teeth witch can easily lead to a complete loss. With prompt diagnosis and correct planification, these lesions can be treated maintaining the tooth and sometimes also tooth's vitality.

Conflict of Interest

No conflict of interest present in the current study.

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SYSTEMATIC REVIEW

Apical debris extrusion and potential risk of endodontic flare-up: correlation with rotating and reciprocating instruments used in daily clinical practice

ABSTRACT

Aim: *During the mechanical and chemical preparation of root canals with reciprocating and rotating instruments, an accidental extrusion of debris beyond the dental apex can be generated. The Nickel-Titanium instruments have drastically improved the clinical procedures and the quality of endodontic treatment. The term flare-up is commonly used to indicate a clinical condition in which pain and swelling of the oral mucosa and soft facial tissues are observed following root canal therapy of a dental element.*
Materials and methods: *After raising the PICO question, the research was carried out following PRISMA guidelines. The search engines used were: Pubmed (Medline), EBSCO and Cochrane Library. Randomized controlled trials (RCT) and in vitro studies were included. The research focus was on articles related to the debris extrusion during root shaping with rotary and reciprocating endodontic instruments.*
Results: *Through the application of inclusion and exclusion criteria, 17 articles were selected. The Jadad Scale was used to evaluate the quality of the papers. In the modern literature, conflicting data have emerged regarding the apical extrusion of debris using the two instrumentation techniques taken into consideration. There are no studies that analyze the possible relationship between the apical extrusion and the design of the tip shape of the endodontic instrument; the connection between shaping techniques and the appearance of flare ups should also be investigated.*
Conclusions: *The apical extrusion of debris occurs both with the reciprocating technique and with continuous rotation instruments. Specifically, regarding the ProTaper, Mtwo, Reciproc, WaveOne and Hyflex, there are discordant results in the literature. The ProTaper Universal cause a greater extrusion, compared to the reciprocating ones, while the ProTaper Next are related with a smaller extrusion. In this condition, there is no difference between WaveOne and Reciproc. The association between flare-up and debris extrusion during the shaping phase must be demonstrated with in vivo clinical research. Further studies are needed in the future.*

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Introduction

Endodontic Flare-up: Definition and Etiology

The term flare-up is commonly used to indicate a clinical condition in which pain and swelling of the oral mucosa and soft facial tissues are observed after a root canal therapy of a dental element (1).

It can occur over a period of time that ranges from a few hours to a few days after starting or completing the endodontic treatment; generally, a flare-up episode leads the patient to request an unscheduled check-up appointment, due to the urgency. Common symptoms, such as spontaneous pain, while chewing or beating, and swelling are associated with a transient decrease of the quality of life (1, 2).

In the contemporary scientific literature, various factors have been reported that can possibly influence the appearance of the flare-up: number of clinical sessions necessary to complete the endodontic treatment, intracanal medications, age and gender of the patient, shaping technique, cleaning of the canals and tools used, extrusion of debris beyond dental apex, diagnosis of previous pathology at the pulp and periapical level, and, finally, the microbiological component (3-6). Some medications such as Aceclofenac 200 mg could be preferred as an oral analgesic premedication, before primary root canal treatment in patients with moderate to severe preoperative pain, for efficient management of post-instrumentation pain (7), while there is no clear evidence supporting that preoperative ibuprofen is better than other drugs in reducing the intensity of postendodontic pain (8).

Therefore, during endodontic treatment, there are clinical situations in which an alteration of the balance between the defense of the host and the aggression of microorganisms is observed, with the consequent formation of acute periapical inflammation (4). Sodium hypochlorite (NaOCL) and chlorhexidine (CLX) are two of the irrigating agents that have shown an important antibacterial activity and they contribute to the incidence's reduction of flare-ups (5). Ethylenediaminetetraacetic acid (EDTA) is effective as a rinse to remove the smear layer in the root canal (9).

Rotating and Reciprocating Endodontic Instrument

An accidental extrusion of debris beyond the dental apex can be generated during the mechanical and chemical preparation of root canals with reciprocating and rotating instruments. In most cases, from a clinical point of view, post-operative pain might affect the patient. The debris is basically represented by dentin, necrotic tissue, remaining pulp tissue, microorganisms or irrigating agents which, pushed beyond the apical foramen, cause irritation of the periapical structures (10).

The Nickel-Titanium instruments have drastically improved the clinical procedures and the quality of endodontic treatment. The reciprocating movement consists in alternating clockwise and counterclockwise rotations, with a different amplitude of the cutting angle (6-16).

The advantage of reciprocating instruments is that they have increased resistance to cyclic fatigue and are disposable for each treatment, lowering the risk of cross-infection and possible fractures (16).

ProTaper files (Dentsply Maillefer, Bellaigues, Switzerland) are rotating instruments characterized by a variable taper that allows progressive preparation in a vertical and horizontal direction; they have a triangular section with three convex cutting angles (11-13).

Mtwo files (Sweden & Martina) have a helical section with cutting blades parallel to the axis of the instrument and a non-active tip. The basic series (standard set) of Mtwo rotary files includes four instruments with variable tip sizes ranging from no. 10 to no. 25, tapers ranging from .04 to .06-.07 and two lengths: 21 and 25 mm. Also file tips range in size from 30, 35, 40 and tapers of 0.5, 0.4 and 0.7 are available (12). OneShape instruments are single files designed for root canal shaping, elaborated by Micro Mega, with a diameter of 25 and single use for patient; they reduce the risk of cross-infection and the timing of

treatment (17). RaCe instruments are rotatory files. They have exclusive advantages including a patented alternating cutting edge/non-screw in design, electropolished finish, and triangular cross section. These features maximize flexibility, cutting efficiency/debris removal and safety (12).
Revo-S are rotatory files with an asymmetrical cross-section that provides less stress on the instrument. The canal axis has 3 cutting edges located on 3 different radiuses. The smaller section allows more flexibility and offers a better ability to negotiate curves. The asymmetrical cross-section increases the available volume for upward debris elimination (12, 18).
Neolix (Châtres-la-Forêt, France) is a newly introduced NiTi rotary system with full rotary motion that consist of one C1 file for coronal enlargement and three A1 files (with tip size range of #20, #25 and # 40) allowing for canal shaping down to the apex (19).
WaveOne (Maillefer, Switzerland) are reciprocating instruments that come in three dimensions, *21.06, *25.08 and *40.08 (constant taper) and they require a special micromotor (12, 13).
Reciproc files (Dentsply) comes in three sizes, *25.08, *40.05, *50.04, S-shaped section, regressive taper in the first 3 mm at the tip; they shape similar to Mtwo and they are used with reciprocating movement and require a special micromotor (12-14).
Hyflex files (Coltene-Whaledent, Switzerland) are characterized by an important control of shape memory and elasticity during shaping (12, 13).

Systematic Review Tool. PICO Question.
The PICO question (Population, Intervention, Comparison, Overcome) aims to investigate the correlation between reciprocating and rotating endodontic instruments and the apical extrusion of debris during the shaping phase of the root canal treatment that could lead to the appearance of postoperative flare-ups.
P: Patients undergoing endodontic therapy with rotary instruments (ProTaper, Mtwo, OneShape).
I: formation of debris during the canal shaping phase.
C: Patients undergoing endodontic therapy with reciprocating instruments (WaveOne, Reciproc, Hyflex).
O: debris extrusion beyond dental apex and the related potential risk of causing flare-ups.

Justification of the Systematic Review
In the modern scientific literature, there are systematic reviews that analyze the connection between apical extrusion of debris, flare-up and the type of endodontic instruments used during the root canal shaping phase. The need to develop this study arises from the desire to update and deepen the subject in the light of the numerous studies published in the last decade, between 2011 and 2021.
Compared to the recent systematic reviews, new articles have been included which provide a detailed reading key on the analyzed topic and satisfy the pre-established criteria of inclusion. Furthermore, in the literature there are diametrically opposed and contrasting results regarding the subject (20, 21).
Therefore, the main goal of the systematic review is to analyze the contemporary studies in a global and rational way and try to provide guidelines to be applied in daily clinical life.

Materials and Methods

The systematic review was reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and it was performed applying meticulously the Handbook Cochrane recommendations (22, 23). The study has been previously registered on PROSPERO platform with code number (341112).

Search Strategy
The systematic review was conducted between 1 July 2021 and January 2022. The primary sources were selected through the use of search engines, such as Pubmed (Medline), EBSCO and Cochrane Library. Alternative sources, such as opengray literature, Google Scholar and bibliograph-

ic indexes of previous systematic reviews, related to the topic, have been consulted. A last research for a partial records update was performed on 6 June 2022. The Boolean operators used are "AND" and "OR".
Different types of keywords were used based on the analyzed context:

- Group 1: (Apical debris OR detritus extrusion OR apical extrusion OR debris extrusion OR flare up);
- Group 2: (WaveOne OR Reciproc OR Hyflex OR reciprocating OR reciprocating file);
- Group 3: (ProTaper OR Mtwo OR One-Shape OR rotary instrument OR rotary file).

The terms of group 1 and group 2, and those of group 1 with group 3 were combined; in both cases the Boolean operator AND was used (table 1).
The NOT operator was not taken into consideration during the research phase.

Articles Selection
Prior to the process of selecting scientific articles for carrying out the systematic review, the inclusion and exclusion criteria were determined.
Inclusion criteria:

- Randomized controlled studies, cohort studies, case-control studies, cross-sectional studies, in vitro studies.
- Patients with endodontic treatment performed through the use of rotating and reciprocating systems.
- Studies that analyze dental elements belonging to the permanent dentition.
- In vivo studies in which endodontic treatments were performed with appropriate isolation (rubber dam).
- In vivo studies in which root canal irrigation protocols with NaOCL or CLX and EDTA were applied.
- Articles in English.

Exclusion criteria:

- Animal studies, clinical cases, systematic reviews, meta-analyzes.
- Studies not available with full text.
- Studies in which no distinction is made between reciprocating and rotating systems.
- Studies analyzing endodontic therapies in temporal dentition.
- Studies with endodontic therapies without rubber dam isolation.
- Studies with endodontic treatments carried out using only manual technique.
- Studies without the control group.
- Studies in which dental elements are characterized by the presence of open apex, cracks or micro fractures, root caries.

In the research phase of the scientific articles, no time restrictions were applied regarding the dates of publication of the sources.

Data Collection
Three operators (F.A.V, A.S, F.Z) independently managed the research and screening of the sources, applying the previously described inclusion and exclusion criteria. The results were compared and extracted; in case of discrepancies, a Senior Author (C.P) was consulted in order to find a fair and thoughtful compromise. The data were collected by compiling tables of results. No metaanalysis or statistical investigations were expected for this study.

Evaluation of the Quality of the Studies
The qualitative evaluation (table 2) of the selected articles was carried out using established indices depending on the type of study.
In the case of Randomized Clinical Trials (RCT) various Scales can be used, including that of Delphi, Jadad and Yates. Many quality assessment tools exist in the literature; however, none cover all the critical aspects of in vitro studies (24).
Some of them could be adapted and applied to evaluate and assess the quality of in vitro studies (24).
The Jadad Scale has demonstrated the best evidence of validity and has been used in over 15,000 scientific studies published in the literature. It mainly focuses on the adequacy of randomization, double blindness and loss of patients' follow up (25).
The final score, assigned through points, can vary between 0 and 5; an article is considered valid, from a qualitative

Table 1

Search String on Pubmed (Medline)

Group 1 AND Group 2	((("apical"(All Fields) OR "apically"(All Fields) OR "apicals"(All Fields) OR "apices"(All Fields)) AND "debris"(All Fields)) OR ("detritus"(All Fields) AND ("extrusion"(All Fields) OR "extrusions"(All Fields))) OR (("apical"(All Fields) OR "apically"(All Fields) OR "apicals"(All Fields) OR "apices"(All Fields)) AND ("extrusion"(All Fields) OR "extrusions"(All Fields))) OR ("debris"(All Fields) AND ("extrusion"(All Fields) OR "extrusions"(All Fields))) OR (("flare"(All Fields) OR "flares"(All Fields)) AND "up"(All Fields))) AND ("WaveOne"(All Fields) OR ("reciproc"(All Fields) OR "reciprocal"(All Fields) OR "reciprocality"(All Fields) OR "reciprocally"(All Fields) OR "reciprocals"(All Fields) OR "reciprocate"(All Fields) OR "reciprocated"(All Fields) OR "reciprocates"(All Fields) OR "reciprocating"(All Fields) OR "reciprocation"(All Fields) OR "reciprocations"(All Fields) OR "reciprocator"(All Fields) OR "reciprocators"(All Fields) OR "reciprocities"(All Fields) OR "reciprocity"(All Fields)) OR "Hyflex"(All Fields) OR ("reciproc"(All Fields) OR "reciprocal"(All Fields) OR "reciprocality"(All Fields) OR "reciprocally"(All Fields) OR "reciprocals"(All Fields) OR "reciprocate"(All Fields) OR "reciprocated"(All Fields) OR "reciprocates"(All Fields) OR "reciprocating"(All Fields) OR "reciprocation"(All Fields) OR "reciprocations"(All Fields) OR "reciprocator"(All Fields) OR "reciprocators"(All Fields) OR "reciprocities"(All Fields) OR "reciprocity"(All Fields)) OR (("reciproc"(All Fields) OR "reciprocal"(All Fields) OR "reciprocality"(All Fields) OR "reciprocally"(All Fields) OR "reciprocals"(All Fields) OR "reciprocate"(All Fields) OR "reciprocated"(All Fields) OR "reciprocates"(All Fields) OR "reciprocating"(All Fields) OR "reciprocation"(All Fields) OR "reciprocations"(All Fields) OR "reciprocator"(All Fields) OR "reciprocators"(All Fields) OR "reciprocities"(All Fields) OR "reciprocity"(All Fields)) AND ("filing"(MeSH Terms) OR "filing"(All Fields) OR "file"(All Fields))))
Group 1 AND Group 3	((("apical"(All Fields) OR "apically"(All Fields) OR "apicals"(All Fields) OR "apices"(All Fields)) AND "debris"(All Fields)) OR ("detritus"(All Fields) AND ("extrusion"(All Fields) OR "extrusions"(All Fields))) OR (("apical"(All Fields) OR "apically"(All Fields) OR "apicals"(All Fields) OR "apices"(All Fields)) AND ("extrusion"(All Fields) OR "extrusions"(All Fields))) OR ("debris"(All Fields) AND ("extrusion"(All Fields) OR "extrusions"(All Fields))) OR (("flare"(All Fields) OR "flares"(All Fields)) AND "up"(All Fields))) AND ("protaper"(All Fields) OR "protapers"(All Fields) OR "Mtwo"(All Fields) OR "OneShape"(All Fields) OR (("rotaries"(All Fields) OR "rotary"(All Fields)) AND ("instrument"(All Fields) OR "instrument s"(All Fields) OR "instrumentation"(MeSH Subheading) OR "instrumentation"(All Fields) OR "instruments"(All Fields) OR "instrumented"(All Fields) OR "instrumenting"(All Fields))) OR (("rotaries"(All Fields) OR "rotary"(All Fields)) AND ("filing"(MeSH Terms) OR "filing"(All Fields) OR "file"(All Fields))))

point of view, when the score is equal to or greater than 3. The bias risk is low when the score is 4-5, moderate when the scores is 3 and high when the score is between 0-2 (25).

In the first three questions, relating to randomization, double blind and follow up, 1 point is assigned respectively if the article satisfies the requirements of the Scale, 0 points otherwise. In the fourth and fifth questions, relating to the adequacy of randomization and blindness, in case of a positive outcome a point (+1) will be assigned, otherwise a point (-1) will be removed. Randomization is the only system that increases the probability of an equal, balanced and uniform distribution of the variables that affect a search result.

Furthermore, it is believed that the loss or absence of patients' follow up can alter the validity of a study when it is greater than 20% (25).

Results

Search and Selection

Using the MeSH and non-MeSH terms and applying the search strategy previously described, a total of 698 articles were selected through search engines, such as Pubmed (Medline), EBSCO and Cochrane Library (Figure 1). Through Pubmed search, combining group 1 and group 2 terms, 177 articles were obtained, while 365 articles were selected by creating a search string between group 1 and group 3. The search through the Cochrane Library led to a total of 81 articles with the combination of group 1 AND group 3 and 35 articles with the combination of group 1 AND group 2. The search through the EBSCO led to a total of 24 articles with the combination of group 1 AND group 3 and 16 articles with the combination of group 1 AND group 2. Once the duplicates have been eliminated, the first identification phase ends with a total

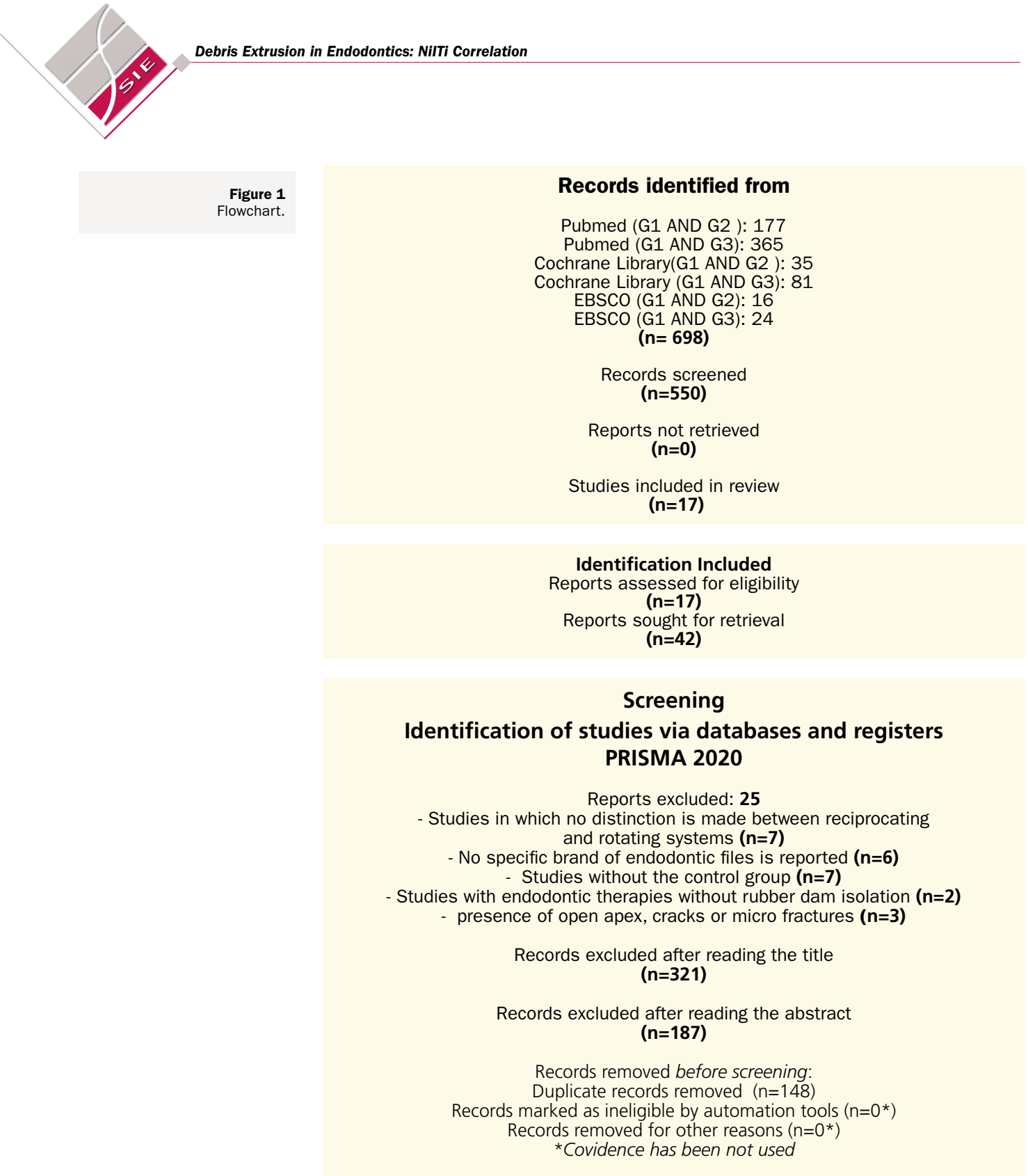

Figure 1
Flowchart.

of 550 articles. Duplicates have been removed using the "Systematic Review Assistant-Deduplication Module" (26), a specific tool developed in 2013. During the screening phase, 321 articles were deleted after reading the title, while 187 were excluded after reading the abstract. Therefore, the previously described inclusion and exclusion criteria were applied to a total of 42 full-text articles potentially relevant to the development of the review.
The methodological criteria for eligibility

Table 2

Evaluation of the Quality of the Included Articles

Authors/Year	Randomization	Double Blind	Follow up	Appropriate Randomisation	Appropriate Blinding	Total score Article Quality Bias Risk
Relvas et al. 2016 (10)	YES	YES	YES	YES	NR	4/5 Low
Shokraneh et al. 2017 (11)	YES	YES	YES	YES	NR	4/5 Low
Surakanti et al. 2014 (13)	YES	YES	YES	NR	NR	3/5 Moderate
Kherlakian et al. 2016 (14)	YES	YES	YES	YES	NR	4/5 Low
Çiçek et al. 2016 (20)	YES	YES	YES	YES	NR	4/5 Low
Neelakantan et al. 2015 (27)	YES	YES	YES	NR	YES	4/5 Low
Bürklein et al. 2013 (28)	YES	YES	YES	NR	NR	3/5 Moderate
Vivekanandhan et al. 2016 (29)	YES	YES	YES	NR	NR	3/5 Moderate
Eliasz et al. 2020 (30)	YES	NO	NO	YES	NR	2/5 High
Yilmaz et al. 2017 (31)	YES	YES	YES	NR	NR	3/5 Moderate
De-Deus et al. 2015 (32)	YES	YES	YES	YES	NR	4/5 Low
Küçükyilmaz et al. 2014 (33)	NO	YES	YES	NR	NR	2/5 High
El Khodary et al. 2019 (34)	YES	YES	YES	NR	NR	3/5 Moderate
Labbaf et al. 2017 (35)	YES	YES	YES	NR	NR	3/5 Moderate
Shahi et al. 2016 (36)	YES	YES	YES	YES	NR	4/5 Low
Ozsu et al. 2014 (37)	YES	YES	YES	NR	NR	3/5 Moderate
Silva et al. 2014 (38)	YES	YES	NO	YES	NR	3/5 Moderate

NR: No Reported. In the total score section, the green color indicates a good scientific validity of the article (=or>3); the red color is associated with a limited validity.

determine the definitive inclusion of 17 articles, which will subsequently be subjected to quality assessment using determined indices and from which the data will be extracted.

Graphic Representation of the Research Results

The explanatory table of the articles used for carrying out the systematic review is shown below. The first author is reported for each study; the year of publication; the country of origin; the Journal (Impact Factor correlated) where the paper has been published; the research size sample; which can be referred to the number of patients or dental elements treated; the endodontic instruments considered in the article; the type of movement, that is rotating or reciprocating; data collection; the clinical diagnosis that led the authors to perform root canal therapy or if they are in vitro studies, and finally, the clinical and statistically significant data reported in the selected articles.

Table 3A

Results Table: studies on patients

Authors/ Year Country	Journal Impact Factor (IF) 2021-2022	Sample size	Endodontic Instruments	Data Collectio Methodology	Preoperative Diagnosis	Relevant Conclusions Reported
Relvas et al. 2016 (10) Brazil	Clinical Oral Investigations IF: 3.573	78 mandibular molars	Protaper Reciproc	Questionnaire to evaluate the Verbal Rating Scale	Asymptomatic pulp necrosis	No significant difference between the two techniques regarding post-operative pain and flare-up
Shokraneh et al. 2017 (11) Iran	Clinical Oral Investigations IF: 3.573	96 patients	Protaper Universal WaveOne Manuals	Questionnaire to evaluate the Visual Analogue Scale	Pulp necrosis with periapical lesion	The group of patients treated with the reciprocating system reported less post-operative pain. No flare up
Kherlakian et al. 2016 (14) Brazil	Journal of Endodontics IF: 4.171	210 patients	ProTaper WaveOne Reciproc	Questionnaire to evaluate the Visual Analogue Scale	Vital dental elements. Root canal treatment performed due to prosthetic reasons	No difference between the instruments analyzed regarding post-operative pain and the need for analgesic therapy
Çiçek et al. 2016 (20) Turkey	Journal of Applied Oral Science IF: 2.698	90 patients	ProTaper WaveOne	Questionnaire to evaluate the Visual Analogue Scale	Asymptomatic, necrotic teeth with radiographic periapical lesion	There is no significant difference between the two techniques in terms of post-operative pain
Neelakantan et al.2015 (27) India	Clinical Oral Investigations IF: 3.573	624 patients	OneShape Reciproc	Questionnaire, the Mann-Whitney Scale and chi-squared test	Symptomatic irreversible pulpitis	The reciprocating technique is associated with a lower intensity and duration of post-operative pain than the rotating one
Shahi et al. 2016 (36) Iran	Iranian Endodontic Journal IF: 1.13	78 mandibular molars	ProTaper RaCe	Questionnaire to evaluate the Visual Analogue Scale	Irreversible pulpitis without radiographic periapical lesions	No significant difference between the two groups regarding the extrusion of debris

Interpretation of the results

The results obtained show discrepancy in the data collected. The articles included in the systematic review are 17. Of these, 11 are in vitro studies (13, 28-35, 37, 38) and 6 randomized controlled trials (10, 11, 14, 20, 27, 36). The time span covered by the research is approximately 8 years, being the oldest article dating back to 2013 (28) and the most current one to 2020 (30). From a geographical and epidemiological point of view, four articles are from Brazil (23,5%), four from Turkey (23,5%), three

from Iran (17,5%) and India (17,5%), one from Poland (6%), Germany (6%) and Egypt (6%). Several Journals have been consulted during data collection; the one with greater impact factor was Journal of Clinical Medicine (30), the lower one was Iranian Endodontic Journal (34, 35); one Journal has no impact factor reported (34). The sample size in RCT varies from 624 (27) to 90 patients (20). In vitro studies, the greater size was 90 (31), the lower was 45 teeth (33). One article analyzes incisor (31), four articles are focused on premolars (13, 33, 37, 38) and four are about molars (28, 32, 34, 35). One articles do not differentiate between dental elements (30) and one analyze monoradicular teeth (29).
In RCT, four articles employ questionnaire to evaluate the Visual Analogue Scale (11, 14, 20, 36), one the Verbal Rating Scale (10) and one the Mann-Whitney Scale (27).
The reason why a root canal therapy was performed was pulp necrosis (10, 11, 20), irreversible pulpitis (27, 36) and prosthodontic reasons (21).
Except for one study where analysis of CBCT sections has been used to determinate debris apical extrusion (30), all in vitro studies have been developed using extracted teeth and measuring the weight difference of Eppendorf tubes (13, 29-31, 33-35, 37) or specific vials (28, 32, 38) before and after the root canal treatment.

Discussion

The main goal of the systematic review was to investigate the possible correlation between the debris extrusion beyond the dental apex and the manifestation of the postoperative flare-up depending on whether the root canal shaping was performed using rotary or reciprocating endodontic instruments.
After the analysis of the data (Table 3A, 3B), it was evident that the reciprocating and rotating techniques are associated with apical extrusion of debris. In the study by Relvas et al (10), no differences in postoperative pain are reported between the two techniques, while Shokraneh et al (11) report that the intensity and duration of pain is reduced in those cases where root canal therapy was performed with reciprocating instruments. In both cases, no post-treatment flare up episodes are reported.
Therefore, In modern scientific literature, conflicting data emerge regarding the topic in question; Kherlakian et al (14) and Çiçek et al (20) reported, as in the case of Relvas et al (10), that there is no difference between the instruments analyzed regarding post-operative pain and the need for analgesic therapy once the treatment is completed, contrary to what is reported by Neelakantan (27), where the shaping with reciprocating is related to a lower intensity and duration of postoperative pain compared to that with rotating ones.
Comparin et al (39), analyzing the Mtwo and Reciproc systems, did not report differences in the incidence, intensity and duration of postoperative pain with time intervals at 24-48-72 hours. Similar data have been descripted by Keskin et al (40), where there are no differences regarding postoperative pain in those cases where a glide path is performed with a rotating or reciprocating system.
Pasqualini et al (41), in their randomized clinical study, focusing on ProTaper and WaveOne, demonstrated that the reciprocating system is associated with greater discomfort in the immediate post-operative period and in cases of previous periapical inflammation compared to the rotating one. Also in the meta-analysis of randomized clinical trials performed by Hou et al (42), rotary systems are associated with a lower incidence of postoperative pain than reciprocating instruments.
In relation to the extrusion of debris beyond the dental apex depending on the technique used, conflicting data emerged. In the study by Surakanti et al (13), WaveOne instruments, when compared with ProTaper and Hyflex, lead to a greater accumulation of debris beyond apex with the risk of originating post-treatment inflammatory reactions. Vivekanandhan

Table 3B

Results Table: in vitro studies

Authors/ Year Country	Journal Impact Factor (IF) 2021-2022	Sample size	Endodontic Instruments	Data Collection Methodology	Preoperative Diagnosis	Relevant Conclusions Reported
Surakanti et al. 2014 (13) India	Journal of Conservative Dentistry IF: 4.146	60 mandibular premolars	ProTaper Hyflex WaveOne	Eppendorf tubes and pre/post treatment weight measurement	In vitro study Extracted elements	More debris extrusion with Waveone instruments than ProTaper and Hyflex
Bürklein et al. 2013 (28) Germany	International Endodontic Journal IF: 5.264	80 mandibular central incisors	Reciproc Mtwo F360 OneShape	Specific vials whose weight was measured before and after the instrumentation	In vitro study Extracted elements	Greater debris extrusion in the Reciproc group
Vivekanandhan et al. 2016 (29) India	Journal of Conservative Dentistry IF: 4.146	60 monoradicular teeth	ProTaper Universal WaveOne Revo-S	Eppendorf tubes and pre/post treatment weight measurement	In vitro study Extracted elements	No difference between ProTaper and WaveOne regarding the extrusion of debris; minor in the case of Revo-S files
Eliasz et al. 2020 (30) Poland	Journal of Clinical Medicine IF: 5.583	60 dental elements	ProTaper Next WaveOne	CBCT sections of a specific area of the root compared before/after shaping	In vitro study Extracted elements	Greater transport of debris beyond the apex with ProTaper Next; WaveOne ensure a more conservative and retentive preparation
Yilmaz et al. 2017 (31) Turkey	Journal of Endodontics IF: 4.171	90 upper central incisors	ProTaper Next Reciproc Twisted Files adaptive	Eppendorf tubes and pre/post treatment weight measurement	In vitro study Extracted elements	Greater extrusion of debris beyond apex with Reciproc compared with ProTaper Next
De-Deus et al. 2015 (32) Brazil	Clinical Oral Investigations IF: 3.573	80 mesial root of mandibular molars	ProTaper Universal WaveOne Reciproc Manuals	Specific vials whose weight was measured before and after the instrumentation	In vitro study Extracted elements	Greater apical extrusion in the ProTaper group compared to the reciprocating group. No difference between the Reciproc e WaveOne
Küçükyilmaz et al. 2014 (33) Turkey	Brazilian Oral Research. IF: 1.633	45 mandibular premolars	ProTaper Reciproc OneShape	Eppendorf tubes and pre/post treatment weight measurement	In vitro study Extracted elements	Greater extrusion of debris and irrigation solution in the Reciproc group compared to the rotating group
El Khodary et al. 2019 (34) Egypt	Egyptian Dental Journal IF: No reported	63 mandibular molars	ProTaper Next Hyflex	Eppendorf tubes and pre/post treatment weight measurement	In vitro study Extracted elements	No significant difference between the three systems regarding extrusion of debris beyond apex

Table 3B

Results Table: in vitro studies

Labbaf et al. 2017(35) Iran	Iranian Endodontic Journal IF: 1.13	60 mesiobuccal root of upper molar	Protaper Universal Hyflex Reciproc Neolix	Eppendorf tubes and pre/post treatment weight measurement	In vitro study Extracted elements	Hyflex files are associated with less extrusion of debris during the root canal shaping phase; the Reciproc instead cause a greater escape of debris beyond the apex
Ozsu et al. 2014 (37) Turkey	European Journal of Dentistry IF: 3.04	56 mandibular premolars	ProTaper Universal ProTaper Next WaveOne	Eppendorf tubes and pre/post treatment weight measurement	In vitro study Extracted elements	ProTaper Universal have a greater extrusion of debris than the Next and the reciprocating technique
Silva et al. 2014 (38) Brazil	Journal of Endodontics IF: 4.171	45 mandibular premolars	ProTaper Universal WaveOne Reciproc	Specific vials whose weight was measured before and after the instrumentation	In vitro study Extracted elements	No difference between the two reciprocating systems regarding the extrusion of debris; it's greater in case of ProTaper Universal.

et al (29), on the other hand, do not report any differences between ProTaper Universal and WaveOne. The largest apical discharge of debris with the reciprocating technique is also reported by Bürklein et (28), in the specific case of the Reciproc compared to OneShape and Mtwo, by Yilmaz et al (31), which analyzes the ProTaper Next and Reciproc and by Küçükyilmaz (33), where in addition to that of debris, there is also a greater extrusion of irrigating agents in the case of Reciproc compared to ProTaper and OneShape.

Eliasz et al (30), in contrast to the authors previously cited, demonstrate in their study that ProTaper Next cause greater extrusion than WaveOne, due to the more conservative and retentive root canal shaping capacity of the reciprocating instruments.

Nevares et al (43), show in their study that there is not difference between Protaper Next and Reciproc regarding apical extrusion of debris in severely curved canals. Both in the De-Deus (42) and Ozsu (37) study, the ProTaper Universal are attributable to a greater apical extrusion when compared with ProTaper Next and the Waveone (37) and the Reciproc and the WaveOne (32).

Furthermore, it's important to highlight that there are no differences in potential extrusion between WaveOne and Reciproc (32), as also reported by Silva et al (38). On the other hand, Nevares et al (44) demonstrate the Reciproc files produced significantly more debris than WaveOne ($p < 0.05$), and both systems produced a greater apical extrusion of debris than HyFlex CM ($p<0.001$).

The WaveOne Gold system, regarding debris extrusion, outperformed also TRUShape and TruNatomy files in Roshdy et al study (45). Similar results to Silva (38) were also described by Tinoco et al (46), who reported, in an ex vivo study, the extrusion of Enterococcus Faecalis with WaveOne, Reciproc and BioRacer files; in this case the apical extrusion is greater with a rotating system (BioRacer) and there is no difference between the two reciprocating ones.

In Labbaf's study (35), the HyFlex prove to be the best instruments when considering the apical extrusion, while the Reciproc, contrary to what other authors reported (32, 37, 38), cause a greater

leakage than the ProTaper Universal.
El Khodary et al (34), in the analysis of Hyflex and ProTaper Next, and Shahi et al. (36), in the study by ProTaper and RaCe, found no statistically significant differences in terms of extrusion of debris beyond dental apex. The data are in contrast with what described by Capar et al. (47), where in an in vitro study reports that ProTaper Next cause less debris extrusion when compared with Hyflex reciprocating files. The articles considered for carrying out the systematic review did not report data concerning the possible correlation between debris extrusion and flare-up (10, 11, 14, 20, 27). The possible causes of flare ups, reported in the literature, can be associated with: root canal preparation and obturation up to the apical end and not the apical constriction (48), the presence of severe preoperative pain (49), presence of *Fusobacterium Nucleatum* (50), presence of radiolucent periapical lesion prior to the treatment (51-53), asymptomatic irreversible pulpitis in female patients (54) and number of visits necessary to complete the endodontic treatment (55). The main limitation of the systematic review is correlated to the presence of in vitro studies, which have, in certain cases, less scientific validity than clinical studies on patients. There are no studies in the literature that analyze the possible relationship of the extrusion of debris with the design of the tip of the endodontic instrument. In addition, other variables, such as the initial anatomy of the tooth, the number of roots and the instrumentation technique (single, multi-file) have not yet been considered. However, de Oliveiro Escocio et al. (56) reported in their randomized clinical trial that the working length did not influence endodontic postoperative pain in case of pulp necrosis. Regarding the data collection method, the main current method to study the amount of debris in vitro is through specific microbalances that measure the difference in weight of the vials before and after the endodontic instrumentation. It is necessary that in the future further studies be carried out both in vivo and in the laboratory, with a strict control of the bias; the aim is to determine the possible correlation between the extruded debris following root canal shaping with reciprocating and rotating techniques and the phenomenon of post endodontic flare up.
The final goal, that is proposed, is to be able to control all those factors, which depend on the operator and the instruments used, in order to minimize pain and discomfort in the endodontic post-treatment phase.

Conclusions

The apical extrusion of debris occurs both with the reciprocating technique and with continuous rotation instruments. Specifically, regarding the ProTaper, Mtwo, Reciproc, WaveOne and Hyflex, there are discordant results in the literature. The ProTaper Universal cause a greater extrusion, compared to the reciprocating ones, while the ProTaper Next are related with a lower extrusion. In this clinical condition, there is no difference between WaveOne and Reciproc. The association between flare up and debris extrusion during the shaping phase must be demonstrated with in vivo clinical research. Further studies are needed in the future.

Clinical Relevance

The clinical relevance of apical debris extrusion, observed with both reciprocating and rotating instruments, varies among analysed NiTi. Validation of the correlation between debris extrusion and flare-ups during shaping necessitates future in vivo clinical research.

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Conflict of Interest

The authors declare that there is no conflict of interest in the article.

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CASE REPORT

Treatment planning and therapy of a severely compromised two-rooted maxillary central incisor

ABSTRACT

Aim: *This case report presents the diagnosis and therapy of a severally compromised two-canal maxillary central incisor.*
Summary: *Tooth #21 was refereed for treatment. 2D and 3D Radiographic evaluation revealed the presence of a severely compromised two-canal central incisor. Root canal therapy was performed. In the two-year follow-up the tooth was fully functional.*
Key learning points:

- *Meticulous treatment planning and treatment is a valid option even in complicated and compromised cases.*
- *Root canal treatment can provide concrete therapeutical choices even in heavily compromised cases.*

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Introduction

The major goal of endodontic therapy is to three-dimensionally shape, disinfect, and obturate the canal system in order to promote healing of the periapical tissues (1). Clinicians are expected to treat the entire canal system, necessitating robust knowledge of endodontic anatomy. The most common reason of failure is untreated anatomy and is more common in the maxillary molars and mandibular premolars (2).

In the literature, maxillary central incisors are usually referenced as single-rooted teeth (3-5).

The anatomic variation of two roots in a central incisor is rare and sometimes difficult to diagnose. Some cases of two-rooted maxillary central incisors have been reported in the past (6-20). Comprehensive diagnosis and treatment planning are fundamental in these cases for a successful outcome. Nevertheless, in none of the cases previously reported in the literature, the state of the tooth under treatment has been that compromised, as the present case report. As it will be described, in addition to the severe conditions of the tooth treated below, (necrotic pulp, abscess, high mobility, and loss of buccal bone plate) the rare anatomic configuration describes an interesting case report demonstrating the range of action of endodontics and the effectiveness of endodontic treatment in combination to a correct diagnosis and treatment plan.

In the present case, non-surgical endodontic treatment of a severely compromised two-rooted maxillary central incisor was completed.

This case report has been written according to Preferred Reporting Items for Case reports in Endodontics (PRICE) 2020 guidelines (21). PRICE flowchart (Figure 1) and PRICE checklist were followed. The patient was fully informed and agreed for the treatment.

Report

A 21-year-old female Greek patient was referred for the evaluation of a central incisor due to mobility and a fistula present in the buccal area of the #21. The patient had previously completed orthodontic therapy, after which a fixed retainer was placed lingual to the six maxillary anterior teeth. She reported a history of trauma with a fork, after which she began experiencing mobility of the tooth and sensitivity while eating. Clinical evaluation revealed that tooth #21 presented with grade III mobility, pain upon palpation and percussion, and no response to cold or hot stimuli. Furthermore, an active sinus tract was present clinically in the area corresponding with the apex of tooth #21.

Radiographic evaluation with intraoral radiographs revealed the presence of a periradicular lesion in the mesial part of the root, corresponding to irregular anatomy in the same area. The presence also of apical root resorption was evident (Figure 2A). In order to further evaluate the periradicular lesion and the anatomy of the canal system, cone-beam computed tomography (CBCT) was advised. An evaluation of the CBCT images revealed a bifurcation of the root in the medial and apical third into two different roots. The mesio-buccal root appeared to be shorter resorbed apically and with a periapical lesion which was perforating the buccal bone, which made the prognosis of endodontic treatment much worse than initially believed. Each root presented one individual canal, so from the main canal in the coronal area was dividing into two individual canals with exits (Figure 3A-3E). Since no evidence of previous carious lesions were found, the pathology might have occurred due to intense orthodontic movement or a previous trauma which the patient did not recall. The treatment options were either to treat endodontically, or proceed with extraction and restore the #21 area either with a fixed partial bridge or placing an implant.

The patient was informed about the overall condition of the tooth and the

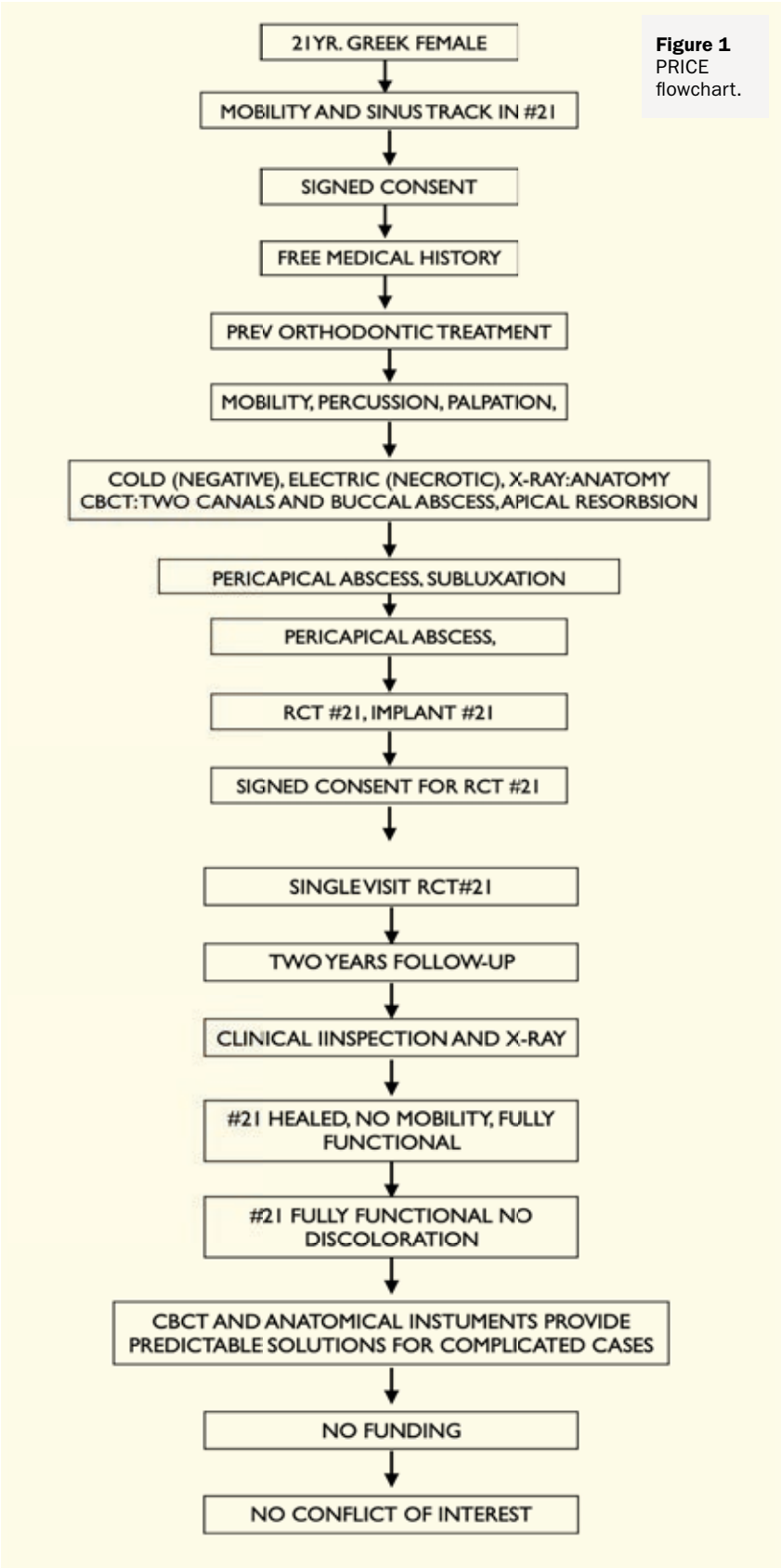


Figure 1 PRICE flowchart.

treatment alternatives. The two more effective and suitable treatment plans were, extraction and implant placement, or root canal therapy in order to maintain the tooth or in the worst case scenario, considering the state of compromission of the whole area of the #21, provide better conditions for a future implant placement (22). She elected to proceed with the more conservative treatment option of saving tooth #21 with a root canal treatment and repositioning of the orthodontic palatal splint, which was broken.

The tooth was anaesthetised, and isolation was achieved by placing a rubber dam over the six maxillary anterior teeth and then isolating the palatal of tooth #21 with a chemical dam. Access was gained with a long round bur mounted in a high speed handpiece. The pulp chamber was found to be dark, characteristic finding of teeth with necrotic pulp, and as expected, void of biological content. Through scouting with a 10k file, the main canal exit was located, and the working length was measured with the use of an apex locator (Morita Root ZX, Tokyo, Japan). Afterwards, the hand file was pre-shaped in the last one millimetre, and the lateral walls were precisely scouted to locate and enter the second mesio-buccal canal of the tooth. The working length of the second canal was also measured with an apex locator. K-files were used to radiographically confirm the working length (Figure 2B). Chemomechanical preparation of both canals was performed with 35.04 rotary files (Race Evo, FKG Dentaire, LaChaux de Fonts, Switzerland). The root canals were copiously irrigated with a 5.25% sodium hypochlorite solution in a Luer lock syringe with an Iriflex (PD, Le Locle, Switzerland) needle. A premixed calcium hydroxide paste was placed into the canals (Multi-Cal, Pulpdent, Watertown, USA) for a week. During the second appointment, calcium hydroxide was removed with an Xp Endo Finisher at 1000 rpm/1 Ncm (FKG Dentaire, LaChaux de Fonts, Switzerland); then, the same file was used to activate a

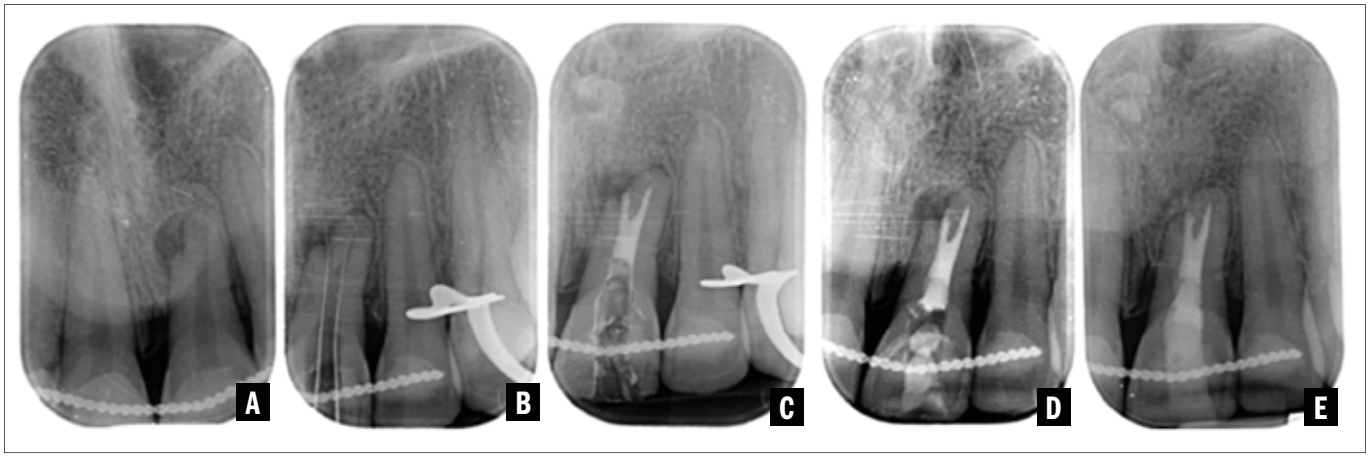


Figure 2
A) Preoperative radiograph: **B)** working length, **C)** obturation, **D)** obturation with temporary filling, **E)** two-year follow-up.

5.25% sodium hypoclorite solution for 30 sec. Afterwards, the canals were irrigated for 2 min with 17% EDTA, which was also activated for 30 sec. The final irrigation was performed with sodium hypochlorite for 3 min. Gutta percha cones were fitted, and the canals were dried with paper cones.
A bioceramic sealer was placed in the canal space (Totalfill BC sealer, FKG Dentaire, LaChaux de Fonts, Switzerland), and then the cones were inserted and cut in the canal orifice using a cold hydraulic technique. (Figure 2C) A temporary filing was placed (Figure 2D), and the patient was referred back to her general dentist for the final restoration and repositioning of the orthodontic splint. Since there were no complaints and due to the restrictions of the COVID-19 pandemic, the follow-up was performed after two years. Clinically, the tooth was functional and stable, and the lesion demonstrated radiographic healing (Figure 2E). After the finishing the treatment and until the follow-up, the patient did not experience any pain or discomfort in the area. In the two year follow-up no discoloration was evidenced in the tooth #21.

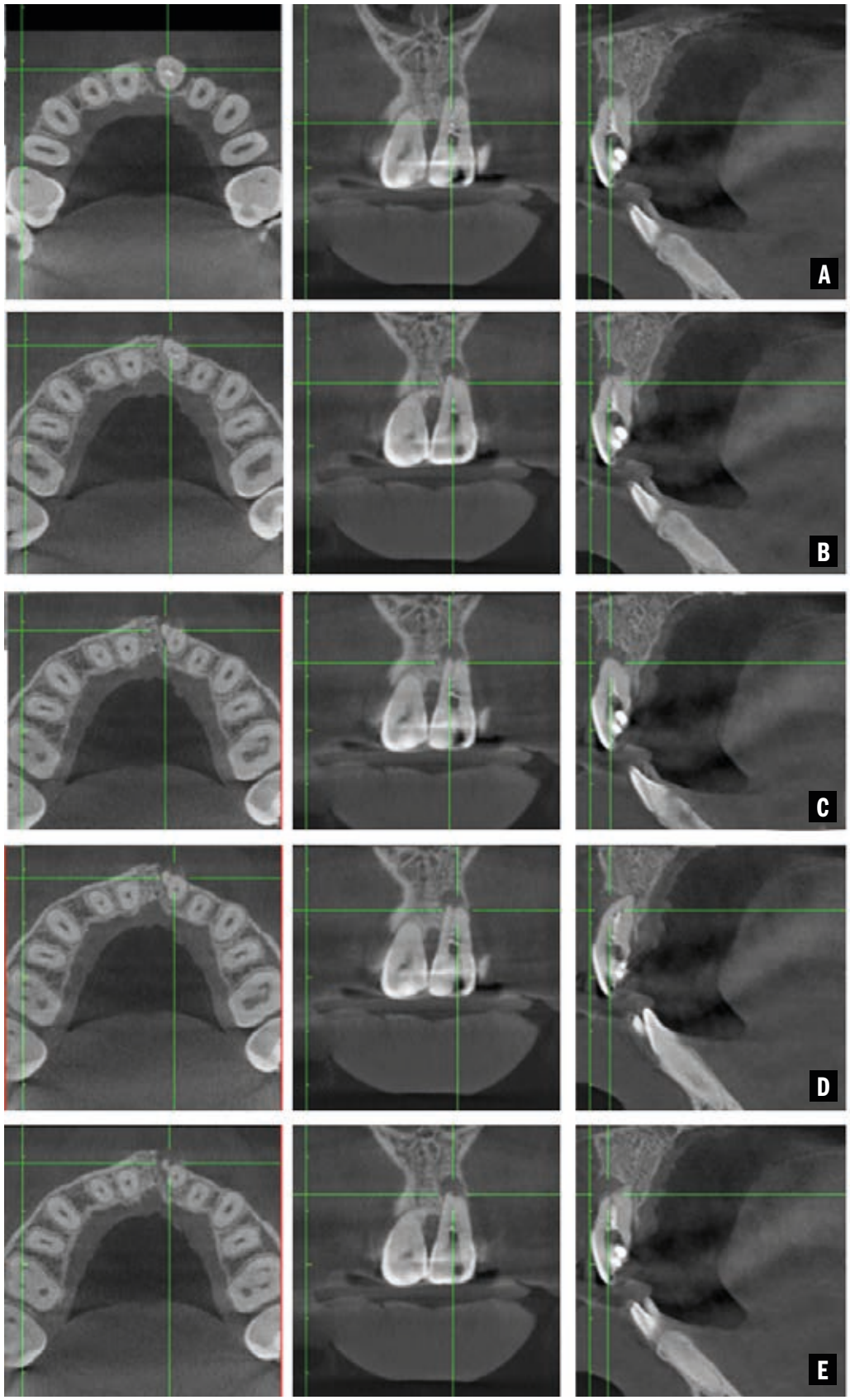
Discussion

The central incisor is typically considered a simple tooth to treat endodontically. Even though the canal space may be excessively wide or narrow due to a history of trauma, the presence of two root canals is rare but must be taken into consideration to avoid a negative outcome. Clinicians should be able to evaluate the case and prepare for anatomical anomalies (23).
Even though the case report is weak of evidence (24), anatomical variabilities are always important to be reported since as mentioned before the main cause of endodontic failure is untreated anatomy (2). After two years of follow-up the tooth presented mobility was absent and periodontal probings measured 3-5 mm (mesial) in the circumference of the tooth. These clinical findings in combination to the radiographic exam, confirmed the healing of the treated tooth. Nonetheless follow-up must continue until at least four years (25). It might be of a great interest also to evidence a three dimensional healing through a second CBCT image, but because of the age of the patient and the absence of other indications this might not be necessary.

Conclusion

In complex cases, treatment planning is fundamental after assessing all the necessary information. In particular, radiographic imaging is essential for the initial evaluation of an endodontic case. In the majority of cases, two-dimensional intraoral radiographs are adequate to assess intracanal anatomy. However, cases with anatomical irregularities or

Figure 3
CBCT slices (sagittal, axial and coronal) from the mesial thrird of #21 **(A)** to apical third **(E)**. The bifurcation of #21 is evident after figure C.



pathologies require the use of CBCT for three-dimensional imaging. CBCT imaging helps assess the anatomy of the canal system and the condition of the periapical tissues (26-29).

Although in many cases, irregularities in the number and shape of the roots are bilateral (30), in the present case, the contralateral central incisor (tooth #11) presented with no anatomical variations upon evaluation by CBCT. Thus, the abnormal anatomy of the central incisor was unilateral in this case.

In addition, the crown of the tooth was normal in shape and identical to the shape of the contralateral central incisor (31). Thus, developmental abnormalities such as gemination and fusion were ruled out.

This case report highlights the importance of treatment planning and meticulous evaluation of the initial internal anatomy of the root canal before initiating endodontic therapy. It is well known that the internal anatomy of each individual tooth is unique, and this must always be taken into consideration while treating a root canal space. Within the limitations of this report, it is important to highlight the ability of the root canal treatment to maintain, heavily compromised anatomically unique teeth.

Clinical Relevance

Meticulous treatment planning and the use of all diagnostic means available, are fundamental for a successful and predictable treatment.

Conflict of Interest

None.

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Written informed consent was obtained from the patient to publish this report in accordance with the journal's patient consent policy.

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CASE REPORT

Restorative challenges and successful outcome of apexification and revascularization in adjacent traumatized immature teeth

ABSTRACT

Aim: *To describe the successful outcome of adjacent traumatized immature teeth treated with revascularization and apexification and discuss some important aspects of regenerative endodontics and restorative alternatives.*

Summary: *An eight-year-old male was referred for endodontic treatment of traumatized teeth #11 and #21. Although revascularization was originally planned for both fractured teeth with pulp exposure, the lack of bleeding into the root canal of tooth #21 changed the treatment plan towards apexification with an apical MTA plug. Seven months later, a glass-fiber post was placed into the root canal of tooth #21 and reinforced with a polyethylene fiber strip. Then, both teeth were restored with multi-layered composite restorations that provided a natural appearance. The three-year follow-up confirmed the absence of painful symptoms and composite infiltration, while CBCT images revealed no root fractures or periradicular lesions, and maintenance of root thicknesses and lengths. Comprehensive restorative treatment can be performed after revascularization or apexification through the collaboration of endodontic and restorative dentistry specialists, which is important to ensure successful outcomes in terms of root development, maintenance of pulp vitality, and pleasant esthetic.*

Key learning points:

- *Dental trauma is a common condition, particularly for children and adolescents, that can lead to several consequences (from tooth discoloration to avulsion).*
- *A flexible plan is crucial to treat traumatized immature teeth.*
- *Revascularization can lead to maintaining root development and avoiding periapical pathologies.*

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Introduction

Accidents and occupational incidents commonly traumatize maxillary anterior teeth of all age individuals (1-3). Accurate pulp and periapical diagnosis based on clinical characteristics and radiographic findings is mandatory to correctly choose between conservative or invasive treatments (4, 5), particularly for immature teeth with an open apex and pulp-related issues (6, 7). Traditional apexification with calcium hydroxide requires multiple treatment sessions, patient compliance, and long-term follow-up; however, the use of mineral trioxide aggregate (MTA) provides an apical barrier for immediate obturation (8).

Regenerative endodontic procedures have gained popularity as an alternative to treating immature teeth with necrotic pulp tissue and immature apices (9-11). However, the description of these procedures as revascularization, regeneration, and revitalization is still questioned (12, 13) since histological studies have shown that the pulp-dentin complex is not truly regenerated (14-16). The revascularization procedure requires bleeding induction into the root canal, which provides a scaffold for stem cells to attach, proliferate, and differentiate into vital components of the pulp-dentin complex (6). Successful cases of revascularized teeth have shown increased root canal wall thickness, apex narrowing, and root lengthening (17-19). However, the intracanal cervical barrier impairs the placement of glass-fiber posts to retain coronal restoration (20).

Composites are versatile restorative materials with biomechanical characteristics that support masticatory loads and optical properties that resemble natural tooth structures (21). Composite restorations can be directly or semi-directly performed by the clinician in a single appointment or manufactured by a lab technician and luted in the second appointment (22). Nevertheless, composite restorations should be incrementally built with small oblique and horizontal layers (21).

The following clinical case describes the successful outcome of apexification and revascularization procedures in a patient with traumatized and necrotic maxillary central incisors and discusses some important aspects of regenerative endodontics and restorative alternatives.

Case Report

This case report was written following the PRICE 2020 guidelines (23). An eight-year-old boy presented to the Endodontics Specialization Course clinic at the University Center of Pará (CESUPA) 20 days after traumatizing both maxillary central incisors. The patient reported mild gum discomfort without intense tooth pain or systemic alterations. Both teeth #11 and #21 presented crown fractures with pulp exposure, negative response to thermal, percussion, and apical palpation, and absence of tooth mobility. Radiographic images revealed incomplete root formation of both #11 and #21 (Figure 1A).

After being properly informed, the patient's legal guardian agreed on the revascularization of both teeth and explicitly approved the anonymous publication of this case report. After infiltrative anesthesia with 2% mepivacaine hydrochloride with 1:100,000 epinephrine (DFL, Rio de Janeiro, RJ, Brazil) and rubber dam isolation, the root canals of both teeth were explored using thin endodontic files (K-file, Dentsply Maillefer, Ballaigues, Switzerland) and irrigated with 2.5% sodium hypochlorite solution (Asfer Industria Química, São Paulo, SP, Brazil). Pulp necrosis was confirmed by the bleeding absence.

A periapical radiograph and an electronic apex locator (Romiapex A-15, Romidan, São Paulo, SP, Brazil) were used to determine the working lengths of both teeth. The root canals were not shaped to preserve dentin tissue; thus, disinfection was obtained through irrigation and intracanal medication (24). An ultrasonic tip (Irrisonic E1, Helse Ultrasonic, São Paulo, SP, Brazil) coupled to an ultrasonic device (Profi Neo, Dabi Atlante, São Paulo, SP, Brazil) was carefully inserted at 2 mm from the working length to passively agitate a 2.5% sodium hypochlorite solution, a 17% EDTA

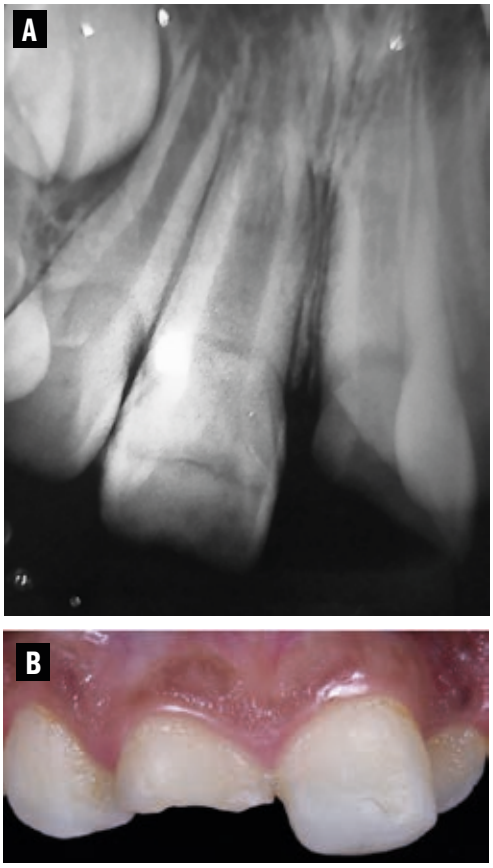

Figure 1
A) Initial periapical radiograph of teeth #11 and #21; **B)** Clinical aspect after endodontic treatments.

solution, and once again a 2.5% sodium hypochlorite solution (three 20-sec times each solution). Then, a calcium hydroxide paste (Calen, SSWhite Duflex, Rio de Janeiro, Brazil) was placed into both root canals, and the coronal accesses were sealed with glass ionomer cement (Maxxion R, FGM, Joinville, Santa Catarina, Brazil).

The intracanal medication was removed after 15 days by agitating a 2.5% sodium hypochlorite solution against the root canal walls with the aid of thin endodontic files. After repeating the abovementioned ultrasonic irrigation protocol, the root canals were irrigated with 20 mL of 17% EDTA to optimize smear layer removal and dried with sterile absorbent paper points. A #30 sharp-edged file (Hedstrom, Dentsply Maillefer, Ballaigues, Switzerland) was manually used to induce bleeding into the root canal of tooth #11; thus, a collagen sponge (Hemospon, Maquira, Paraná, Brazil) was placed into the root canal middle third to enhance blood clotting. Since bleeding into the root canal of tooth #21 was not achieved despite multiple attempts, the treatment plan was modified to apexification. Then, MTA plugs (MTA Repair HP, Angelus, Paraná, Brazil) were placed at the cemento-enamel junction (CEJ) level of tooth #11 and at the apical root third of tooth #21. Finally, both root canals were cleaned and the root accesses were temporarily sealed with glass ionomer cement and layered with composite to minimize the risk of contamination (Figure 1B).

The patient attended to the first follow-up appointment only after seven months due to COVID-19 pandemic restrictions and reported no pain or discomfort since then. Cone beam computed tomography (CBCT) images revealed complete apex closure for both teeth without pathology signs (Figure 2).

After rubber dam isolation, the temporary root sealing of tooth #21 was removed. A glass-fiber post was cleaned with 70% alcohol and received two layers of silane (Prosil, FGM). After 2 min and 30 sec wait after each silane application, an adhesive resin layer (Ambar Universal APS, FGM) was applied for 30 sec on each surface of the post (buccal, palatal, and tip). The tip of the post was layered with a small increment of A2E-shaded composite (Forma, Ultradent, Indaiatuba, SP, Brazil) and passively inserted into the root canal of tooth #21, which was previously lubricated with water-soluble gel, and light-cured for 5 sec. The customized post was removed from the root canal and additionally light-cured for 60 sec, while the root canal was irrigated with saline solution and dried with absorbent paper points. The customized post was cleaned with 70% alcohol and received a layer of adhesive resin (Ambar Universal APS, FGM). After filling the root canal with an A2-shaded dual-curable composite cement (Allcem Core, FGM) dispensed from an auto-mixing syringe, the customized post was placed, the composite cement excess was removed, and the post was light-cured for 60 sec. A periapical radiograph was taken to confirm the proper placement of the customized post into the root canal. The post was sectioned to an appropriate height and the root access was filled with composite (Figure 3A).

After infiltrative anesthesia with 3% prilo-

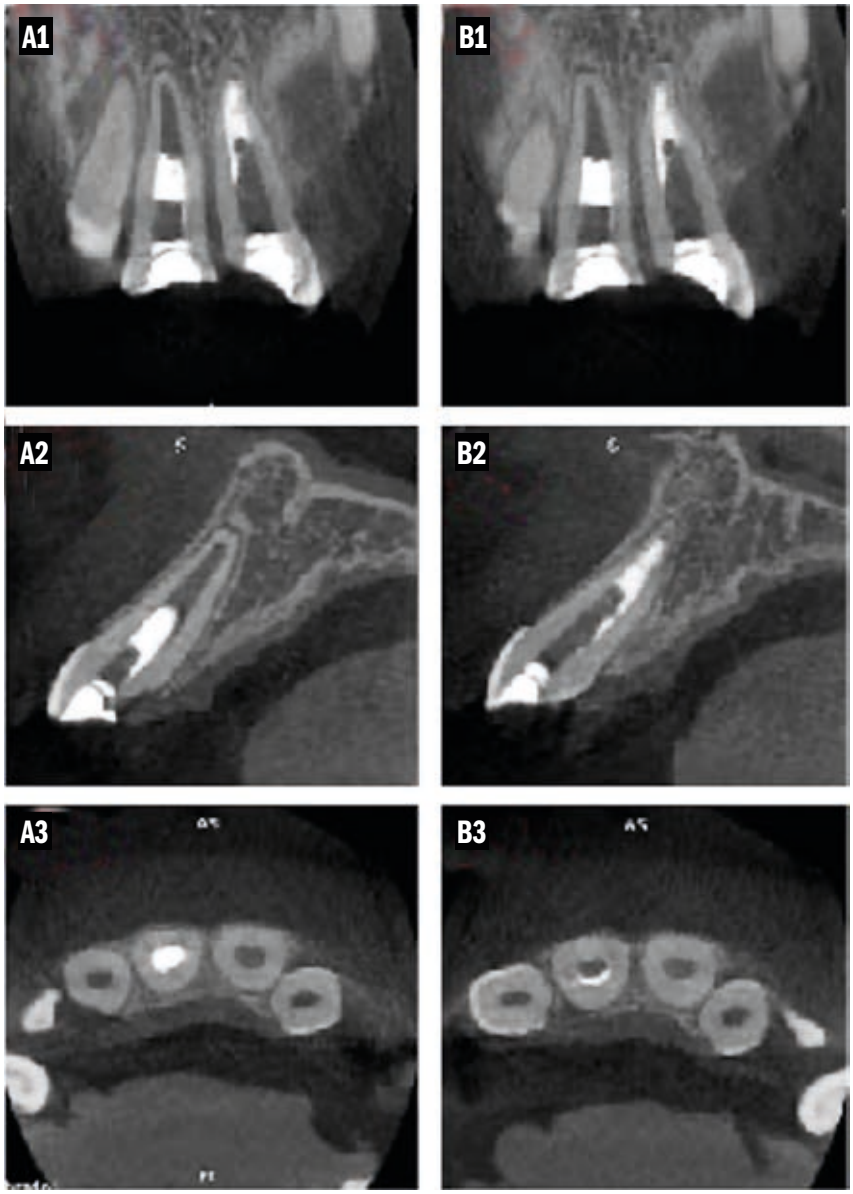

Figure 2
CBCT images of teeth #11 and #21 seven months after endodontic treatments. **A1, A2**, and **A3** Coronal, sagittal, and axial view of tooth #11. **B1, B2,** and **B3** Coronal, sagittal, and axial view of tooth #21.

caine hydrochloride (DFL, Rio de Janeiro, RJ, Brazil), the root canal sealing of tooth #11 was removed using diamond burs (Invicta, American Burrs, Palhoça, SC, Brazil) mounted on a high-speed handpiece and the MTA plug was completely exposed. The surrounding enamel of both teeth was etched with 35% phosphoric acid (Potenza Attacco 35%, PHS Group, Joinville, SC, Brazil) for 30 sec, rinsed, and air-dried. Then, a two-step adhesive system (Scotchbond Universal, 3M ESPE, Saint Paul, MN, USA) was applied and light-cured with an LED unit with an output of 1,300 mV/cm² (Valo, Ultradent). A flowable A2-shaded composite (Filtek Supreme Flowable Restorative, 3M ESPE) was used to seal the root canals. A translucent composite layer (Filtek Z350 XT BT, 3M ESPE) was placed over transparent polyester matrix strips (TDV, TDV Dental, Pomerode, SC, Brazil) to restore the palatal surfaces (Figure 3B). Next, a 3-mm-thick polyethylene fiber strip (Ribbond, OralTech, Ibiporã, PR, Brazil) was placed on the tooth #21 to better stress distribution throughout the subsequent composite layers, which were individually placed with spatulas (Condensa, LM Dental, Quinelato, São Paulo, SP, Brazil), and light-cured for 20 sec. An OPA2-shaded 0.5-mm-thick composite layer (Palfique LX5, Tokuyama, Ibaraki, Japan) was placed over the polyethylene fiber to mimic dentin morphology and reinforce the internal structure (Figure 3C). Then, a translucent composite layer (Filtek Z350 XT BT, 3M ESPE) was placed on the incisal area to reproduce the natural translucency of young teeth (Figure 3C). An EB1-shaded composite layer (Estelite ÔMEGA, Tokuyama) was used to cover the entire buccal surface (Figure 3D).

After removing rubber dam isolation, occlusal contacts under maximum intercuspation and jaw protrusion/excursions were verified with carbon paper (Accufilm, Parkell, New York, NY, USA), and composite excess was removed using fine and extra fine grit diamond burs (#3168 and #3118, American Burrs). Diamond flame- (One Gloss Set, Shofu, Kyoto, Japan) and spiral-shaped tips (Twist Gloss, American Burrs), and 0.5-µm grit paste (Diamond Polish, Ultradent) were used for surface texturing and polishing. The immediate aspect exhibited appropriate color, shape, and light scattering (Figures 3E and 3F).

A three-year follow-up confirmed the absence of painful symptoms and composite infiltration. CBCT images revealed no root fractures or periradicular lesions, and maintenance of root thicknesses and lengths (Figure 4).

Discussion

This case report addresses a relevant dilemma regarding endodontic treatment of

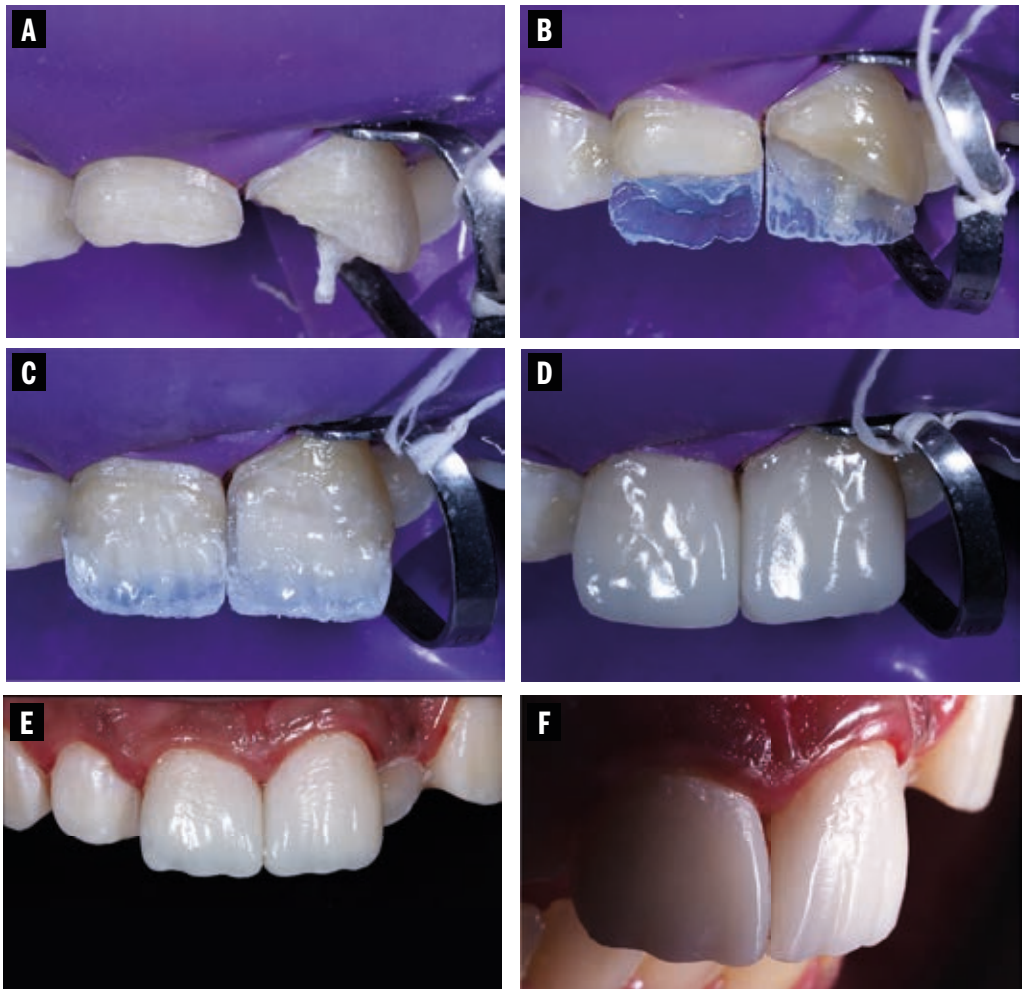

Figure 3
A) Rubber dam isolation with aid of metallic clamp; **B)** Palatal surfaces of both teeth restored with translucent composite and polyethylene fiber placed on tooth #21; **C)** Placement of dentin and incisal composite layers; **D)** Placement of enamel composite layer; **E** and **F)** Clinical aspect after occlusal adjustment, finishing, and polishing.

traumatized teeth, in which a choice between apexification and revascularization has to be made. To the best of the author's knowledge, this is an original case that reported the successful outcomes of both treatments conducted in the same patient and brings valuable insights for clinicians. There are several aspects to be considered in cases of dental trauma and the treatment plan can often change. In this particular case, the lack of bleeding into the root canal of tooth #21 impaired the revascularization to be performed and changed the treatment plan toward apexification. This highlights the importance of clinicians to master diverse treatment approaches for trauma cases. Although the revascularization and apexification protocols used in this study are well-supported in the literature, the treatment choice must be carefully based on individual aspects of patients and clinical indications. In addition, this case addressed the important challenge of restoring a revascularized tooth that often does not allow the placement of intraradicular posts. This case report showed practical solutions and guidance to restore traumatized teeth through the combination of glass-fiber post and esthetic composite restorations.

Accurate diagnosis is essential to establish an adequate treatment plan for immature permanent teeth (25). In this case, conservative pulp treatments were not feasible due to the necrotic pulp status of both teeth; thus, revascularization and apexification were performed to treat asymptomatic apical periodontitis. Moreover, the diagnosis of the young patient was performed by an experienced clinician who used several diagnostic tools and minimized potential complications that can arise from inadequate dental trauma management. Compli-

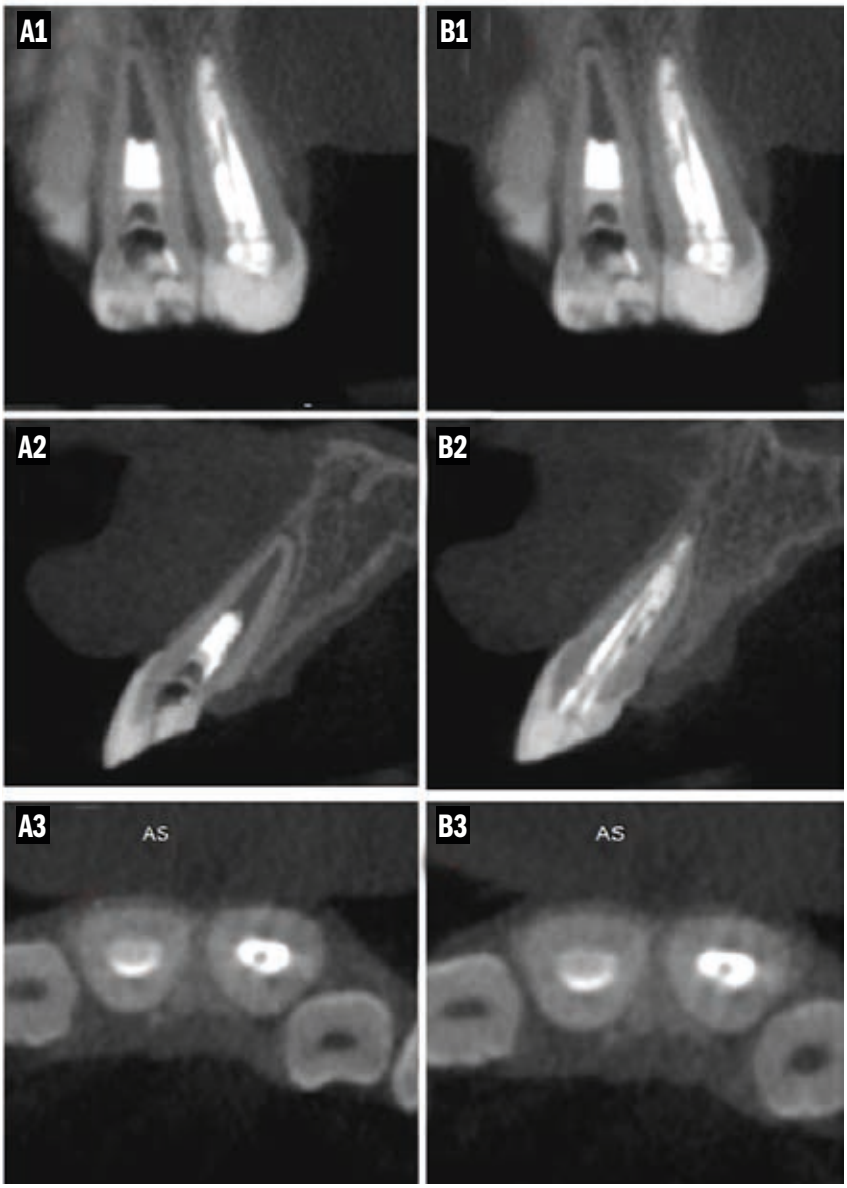

Figure 4
Three-year CBCT follow-up. **A1, A2**, and **A3** Coronal, sagittal, and axial view of tooth #11. **B1, B2,** and **B3** Coronal, sagittal, and axial view of tooth #21.

cations such as root resorption, surface resorption, apical radiolucency, gingival recession, inflammatory resorption, arrested root development, disturbed root development, and pulp necrosis can occur irrespective of the root formation stage (26).

A tooth crown fracture in patients with incomplete apices often requires a multidisciplinary treatment with endodontists and restorative dentistry specialists in order to achieve optimal rehabilitation (18). The revascularization has a similar success rate when compared to apexification with calcium hydroxide and promotes both root length and thickness formation. Moreover, revascularization is less time-consuming and does not require multiple changes of intracanal medication that may weaken tooth structures (20, 25). Nevertheless, the apexification known as the "apical MTA plug" can be completed in a single session and a follow-up appointment after material setting for root canal filling. Although excellent success rates have been reported, the apical MTA plug does not stimulate root development (27, 28). The absence of bleeding despite multiple attempts suggested insufficient blood supply in the root canal of tooth #21 for revascularization; thus, the MTA plug was placed to seal the root apex and prevent bacteria contamination.

A prospective randomized controlled study on 118 patients reported a 100% success rate for both of apexification and revascularization. The revascularization technique demonstrated remarkable root length and thickness improvements of 81.16% and 82.60%, while the apexification technique exhibited only 26.47% and 0%, respectively (29); however, the study only reported a one-year follow-up that seems relatively short for establishing long-term success. In addition, a systematic review with meta-analysis also indicated similar success rates for both techniques performed in immature permanent teeth (20). Although revascularization and apexification are highly effective treatments, the first leads to root length and thickness improvements. Furthermore, the success of these procedures relies on the knowledge of the clinician to deal with incomplete apices. Factors such as inadequate root thickness or length often indicate the need for revascularization and may limit the use of intraradicular retainers (6). Thus, alternative restorative techniques and/or materials must be considered to overcome the limitations of the cervical barrier presence and provide adequate retention (30). An effective coronal sealing plays a key role in revascularization and apexification success since it prevents microleakage of oral microbes and reduces the risk of reinfection (31). The lack of adequate coronal sealing is an important reason for failure; thus, the restorations of revascularized teeth should be often followed up (32).

Regarding the significance of materials in these treatments and the importance of proper coronal sealing, another extremely relevant factor is biomaterials. The success of regenerative endodontic treatments is largely attributed to the properties of these biomaterials. Recent studies emphasize the role of biocompatible and bioactive endodontic sealers, highlighting their cytotoxicity, cell viability, and influence on tissue healing and regeneration. For instance, calcium silicate-based sealers demonstrate superior biocompatibility and bioactivity, enhancing treatment outcomes by promoting cellular responses conducive to tissue repair and growth (33, 34, 35).
Esthetics should also be considered when restoring traumatized teeth with incomplete apices in alignment with evidence-based and patient-specific treatments. Restoring the natural appearance of the maxillary anterior teeth is important for patient satisfaction and self-esteem. Therefore, restorative materials with optimal optical properties and techniques that promote seamlessly integrated them into the remaining tooth structure should be ideally selected. However, esthetic considerations must not overlap with long-term endodontic prognosis. The clinician must carefully balance the immediate benefits of esthetic restorations and the long-term uncertain outcome of regenerative treatments. This emphasizes the need for a reasonable approach that accommodates the further endodontic implications and the esthetic aspiration of the patient.

Conclusion

Predictable rehabilitation protocols are essential in cases of traumatized teeth with incomplete apices. Comprehensive restorative treatment can be performed after revascularization or apexification through the collaboration of endodontists and restorative dentistry specialists, which is important to ensure successful outcomes in terms of root development, maintenance of pulp vitality, and pleasant esthetic. Further clinical trials are needed to improve and validate these treatment protocols for traumatized teeth with incomplete apices.

Clinical Relevance

The study delineates a strategic approach to endodontic treatment of immature teeth, emphasizing rehabilitation aspects. This research aids clinicians in determining the optimal treatment plan for managing teeth with incomplete apex formation, focusing on the potential for natural tissue regeneration and avoiding more invasive procedures. Such insights are pivotal for enhancing clinical outcomes and fostering tooth preservation in the context of dental rehabilitation.

Conflict of Interest

None.

Acknowledgments

The authors declare no financial affiliation, employment, direct payment, stock holdings, retainers, consultantships, patent licensing arrangements, or honoraria, nor any involvement with any commercial organization with a direct financial interest in the subject or materials discussed in this manuscript. Furthermore, there are no other potential conflicts of interest to disclose.
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CASE REPORT

Root canal treatment of a maxillary first molar with unusual anatomy

ABSTRACT

Aim: *To describe the management of a maxillary first molar with six root canals, two in each root.*

Summary: *A 36-year-old male patient presented with a complaint of discoloration and decay on an upper left back tooth. Clinical examination revealed the presence of deep occlusal caries on the maxillary left first molar. A detailed clinical and radiographical examination led to a diagnosis of pulp necrosis with asymptomatic apical periodontitis. Non-surgical root canal treatment was performed. Due to the suspected anatomical variation, Cone beam computed tomography (CBCT) imaging was obtained. CBCT imaging and clinical identification using the DOM revealed the presence of six root canals, two in each root, with the code (^{3}26 MB^{2} DB^{2} P$^{2-1}$) using Ahmed et al. system. Root canal treatment was successfully performed and confirmed radiographically. The tooth was restored with a resin composite restoration. The patient was referred for prosthodontic evaluation for extracoronal restoration.*

Key Learning Points:

- *This case highlights how clinicians must approach root canal treatment with a comprehensive mindset that considers the potential for extraordinary anatomical complexities.*
- *Preoperative knowledge of root canal anatomy and proper armamentarium are mandatory for successful root canal treatment procedures.*

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Introduction

Root canal treatment (RCT) aims to three-dimensionally seal the root canal space after proper sterilization (1). The root canal system refers to the internal space within a tooth that contains pulp tissue. It consists of the pulp chamber located in the anatomical crown of the tooth and the root canals encased within the roots (2-5). This system can be quite intricate, with teeth often displaying extra roots and additional root canals (6). These variations in tooth anatomy can pose challenges during root canal treatment, underscoring the importance of dental practitioners adhering to recommended guidelines for identifying and addressing these canals to ensure the success of RCT (7). The maxillary first molar typically exhibits three roots: the mesiobuccal (MB), distobuccal (DB), and palatal (P) roots (8). In most cases, the MB root contains two root canals (referred to as MB1 and MB2), while each of the distobuccal and palatal roots has a single root canal (9,10). However, it is worth noting that the prevalence of two root canals in the palatal root has been reported ranging from 1.2 to 3% (11, 12), and the presence of a second DB root canal in maxillary first molars falls within the range of 1.1 to 2.5% (11, 13). Table 1 provides a comprehensive overview of the reported cases involving maxillary first molars with six or more root canals (14-23). Recognizing such anatomical variances is essential to prevent the risk of missed canals, which can lead to treatment failure and complications (24). This case study describes an unusual presentation of a maxillary first molar featuring six separate root canals, with two canals in each root. Managing this case underscores the significance of thorough preoperative evaluation and meticulous treatment planning.

Report

History and clinical examination

A 36-year-old male patient from Nepal presented with a complaint of discoloration and decay in the maxillary left posterior tooth (tooth #14 per the Universal numbering system). There was no associated pain, and the patient had no significant medical history. Upon clinical examination, deep occlusal decay was observed on tooth #14. The tooth did not respond to thermal and electrical pulp vitality tests using a Digitest 3 Pulp Vitality Tester (Parkell, Long Island, NY, USA), and it did not exhibit tenderness upon percussion or palpation. Probing depths were within the normal range, and there was no mobility of the tooth. An intraoral periapical radiographic examination revealed a periapical radiolucency along with the loss of lamina dura, in addition to the presence of relatively wide mesiobuccal, distobuccal, and palatal roots, as shown in Figure 1.
Detailed clinical and radiographic assessments led to a diagnosis of pulp necrosis with asymptomatic apical periodontitis. Non-surgical root canal treatment was recommended for tooth #14. Following the diagnosis and formulating the treatment plan, the patient was informed about the procedure, its associated risks and benefits, and written informed consent was obtained.

Clinical management

Local anesthesia using 2% lidocaine with 1:100,000 epinephrine (Septodont, Saint-Maur-des-Fossés, France) was administered, followed by the placement of a rubber dam to isolate the tooth. The access cavity was prepared after removing the caries. Due to suspicions about the anatomy of the relatively wide mesiobuccal, distobuccal, and palatal roots, a cone-beam computed tomography (CBCT) scan was obtained using a Planmeca Promax 3D CBCT machine. The scan was performed with the following parameters: 90 kV, 12 mA, 15 seconds of exposure, a voxel size of 75 µm, and axial sections with a thickness of 0.225 mm. The scan revealed the presence of 6 root canals, with two root canals in each root, as shown in Figure 2.
To examine the pulpal floor and assist in locating the 6 root canal orifices (2 mesiobuccal canals - MB1 & MB2, 2 distobuccal canals - DB1 & DB2, and 2 palatal canals - P1 & P2), a DG-16 probe and Global A6

Table 1

Summary of the reported cases of maxillary first molar showing 6 or more root canals using Ahmed et al coding system (5)

Year	Author	Method of detection	Anatomical classification (Ahmed et al.)
1983	Martínez-Berná & Ruiz Badanelli (14)	Intraoral Periapical Radiographs	^{3}26 MB$^{3-2}$ DB^{2} P^{1}
1988	Bond et al. (15)	Intraoral Periapical Radiographs	^{3}16 MB^{2} DB^{2} P$^{2-1}$
2002	Maggiore et al. (16)	DOM	^{3}26 MB^{2} DB^{1} P^{3}
2007	Adanir (17)	Intraoral Periapical Radiographs	^{4}16 MB^{1}MP^{2-}1 DB$^{2-1}$ P^{1}
2009	de Almeida-Gomes et al. (18)	Intraoral Periapical Radiographs	^{3}26 MB^{2} DB$^{2-1}$ P$^{2-1}$
2010	Albuquerque et al. (3 cases) (19)	DOM	^{3}26 MB$^{2-1}$ DB$^{2-1}$ P$^{2-1}$
2010	Karthikeyan and Mahalaxmi (4 cases) (20)	Intraoral Periapical Radiographs	^{3}26 MB^{2} DB$^{2-1}$ P$^{2-1}$
2010	Kottoor et al. (21)	CBCT and DOM	^{3}26 MB$^{3-2}$ DB$^{2-1}$ P$^{2-1}$
2011	Kottoor et al. (22)	CBCT and DOM	^{3}26 MB$^{3-2}$ DB$^{3-2}$ P$^{2-1}$
2021	Lin et al. (23)	CBCT and DOM	^{3}16 MB^{2} DB^{2} P$^{2-1}$
2023	Singh et al. (Current case)	CBCT and DOM	^{3}26 MB^{2} DB^{2} P$^{2-1}$

dental operating microscope (DOM) (Global Surgical Corporation, St. Louis, Missouri, USA) were used. Once the orifices' locations were confirmed, the working length of the 6 root canals was determined using a Root ZX electronic apex locator (J. Morita, Kyoto, Japan) and subsequently verified with intraoral periapical radiographs, as shown in Figure 3.

The canals were negotiated using #10 and #15 K files (Mani, Utsunomiya, Japan). Cleaning and shaping of the root canals were carried out using the ProTaper Gold rotary system (Dentsply Maillefer, Switzerland) following the manufacturer's recommended speed and torque settings. Copious irrigation was performed using sodium hypochlorite (3%) and EDTA (17%) solutions with a 30-gauge needle NaviTip (Ultradent, UT, USA). The 4 buccal canals, MB1, MB2, DB1, and DB2, were prepared up to the F2 file, while the 2 palatal canals were prepared up to the F3 file. After the instrumentation of all 6 root canals, they were thoroughly dried using paper points. Master gutta-percha cones were clinically verified and confirmed radiographically. The root canals were filled using gutta-percha (Meta Biomed, Chungcheongbuk-do, Korea) in combination with NeoSEALER root canal sealer (Avalon BioMed, Houston, TX, USA).

The two MB and two DB root canals were filled using a single cone technique, while the two palatal root canals were filled using the warm vertical compaction technique. The tooth was restored with a resin composite restoration. The patient was referred for prosthodontic evaluation for an extra-coronal restoration.

Figure 1
Preoperative intraoral periapical radiograph of the left maxillary first molar (Tooth #14).

Discussion

Root canal treatment procedures of molars with complex anatomy is a challenging task, and can lead to complications if not performed successfully (18, 25-27). This case presented the management of an unusual root canal anatomical variation of a maxillary first molar. The CBCT scan revealed the presence of six root canals, an exceptionally rare phenomenon (18).

CBCT is a precise diagnostic tool with minimal radiation exposure, capable of providing detailed views of the root and the root canal anatomy (28-30). It offers three-dimensional images with excellent spatial resolution, making it invaluable for endodontic diagnosis and treatment planning (31, 32). When combined with a DOM, the enhanced magnification further facilitates the visualization of tiny root canal orifices and branching structures originating from the main canals (33).

Earlier studies have established a wide variation of root canal configurations in the maxillary first molars, varying from a single root canal to as many as seven root canals (14, 19, 34, 35). The literature contains reports of eight cases featuring the presence of two root canals in the palatal root of the maxillary first molars (36-41). Additionally, five cases have been documented in the literature where a second distobuccal (DB) root canal was identified in the maxillary first molars (14, 15, 42).

Martinez-Berna and Ruiz-Badanelli (14) reported clinical management of maxillary molars with six root canals. Albuquerque et al reported the successful nonsurgical endodontic treatment of three permanent maxillary first molars, each with three roots and six root canals (19). Almeida-Gomez et al also identified and managed a maxillary first molar encasing six root canals, utilizing similar clinical procedures (18). Kaushik et al detailed the endodontic management of two maxillary first molars, both presenting six root canals, with the aid of a DOM and CBCT (34). While the number of reported cases in the literature featuring maxillary first molars with six or more root canals is limited, the majority of them employed magnification and three-dimensional imaging to identify

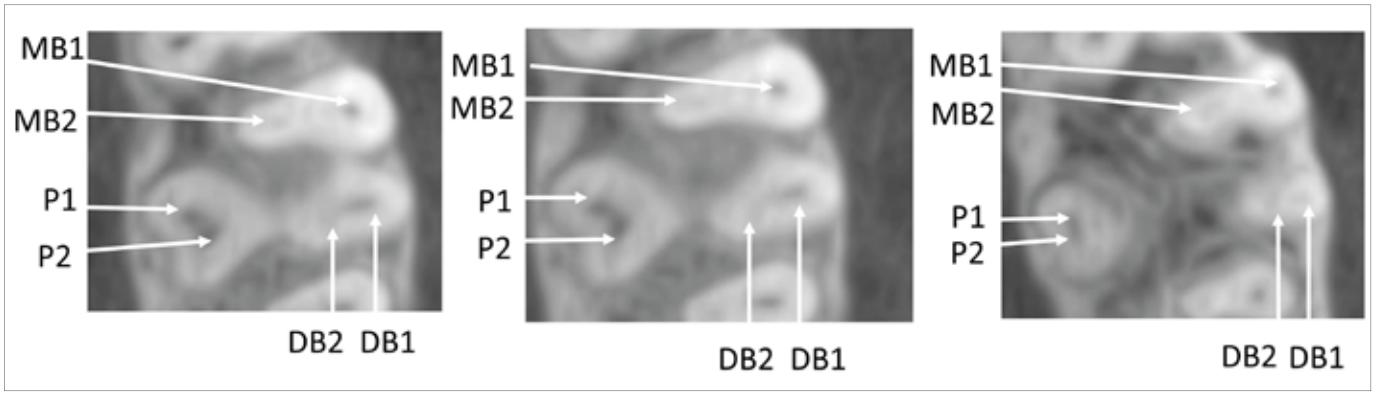

Figure 2
Preoperative cone beam computed tomographic axial views, a) at the coronal one third of the root; b) at the middle one third of the root; c) at the apical one third of the root.

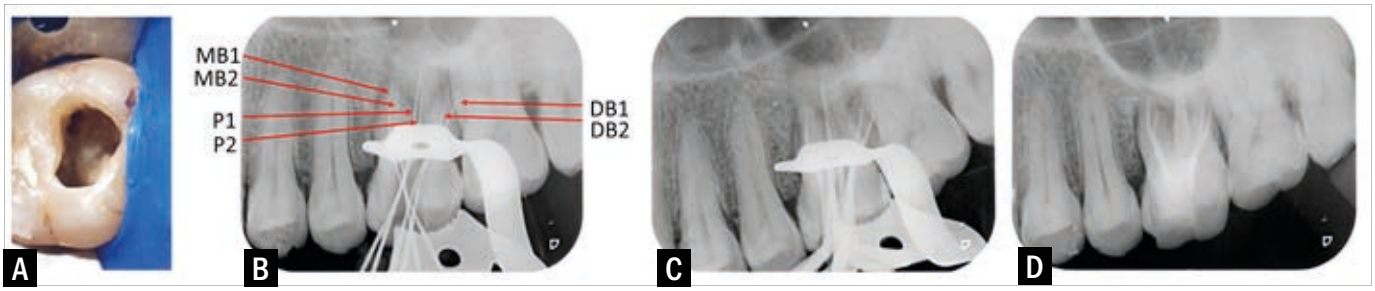

Figure 3
Operative records of the root canal treatment of the left maxillary first molar (Tooth #14) showing root canal morphology $^{3}26$ MB^{2} DB^{2} P$^{2-1}$. **A)** Intraoral photograph of the access cavity preparation; **B)** Intraoral periapical radiograph showing the working length determination; **C)** master cone intraoral periapical radiograph showing six root canals; **D)** postoperative intraoral periapical radiograph.

or confirm this variation. The most common configuration of such cases is the code $^{3}26$ MB^{2} DB^{2} P$^{2-1}$ according to the Ahmed et al system (5). The adoption of the Ahmed system for root canal classification has proven to be valuable in presenting both the number of roots and root canal configuration in a precise and straightforward manner. The accuracy of this coding system has been documented in a recent systematic review (43). One of the contributing factors to such anatomical variations is the difference in the ethnic backgrounds of the populations studied (44). Lin et al pointed out that, among nine case reports of maxillary first molars with multiple root canals published between 2010 and 2020, seven of these cases were documented in India (23). They found that the configuration of multiple canals is more frequently observed in Asian ethnic groups, with most of these cases originating from India. The current case report, featuring a patient from Nepal, provides additional perspectives that reinforce the correlation indicating a higher prevalence of multi-canal configuration in maxillary first molars among individuals of Asian ethnic backgrounds.

This case report underscores the importance of preoperative awareness regarding both typical and atypical anatomical variations in the maxillary first molars. The employment of high-resolution diagnostic instruments, such as CBCT, plays a significant role. Following the latest guidelines for access cavity preparation techniques and conducting a comprehensive examination of the pulp chamber floor are crucial steps in identifying root canal orifices in teeth exhibiting additional canals.

Conclusion

This case report describes the root canal therapy performed on a maxillary first molar with a unique root canal configuration. A comprehensive preoperative evaluation, supported by radiographic imaging and state-of-the-art diagnostic equipment, is indispensable for the recognition and successful treatment of such cases.

Clinical Relevance

Maxillary first molars show a wide variations in the number of root canals. Using 3D diagnostic imaging and the dental operating microscope pave the way for accurate detection of additional canals for teeth scheduled for root canal treatment procedures.

Conflict of Interest

None.

Acknowledgements

None.

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FRONTIERE DELL'ENDODONZIA:
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Lettera DEL PRESIDENTE

Cari Amici, Soci e Colleghi,
come prima cosa vorrei ringraziare tutto il Consiglio Direttivo per il lavoro finora fatto, un ringraziamento particolare al mio e nostro Segretario Katia Greco per il continuo supporto, l'appoggio e l'impegno senza tentennamenti, la capacità operativa e la professionalità con cui ha affrontato il suo compito in un momento di transizione che non ha precedenti nella storia della SIE.
Il 2023 è stato un anno difficile perché abbiamo dovuto affrontare un grande cambiamento nella nostra struttura operativa societaria. Nel 2022, in previsione della inderogabile indisponibilità dal 2023 della sede istituzionale di Milano, il consiglio direttivo passato e la nostra storica segretaria, Gaia Garlaschè, non erano riusciti a trovare un accordo per proseguire la collaborazione che è di fatto cessata a dicembre 2022 con un tempo programmato per il passaggio delle consegne alla nuova segreteria esterna fino al 31 marzo 2023. Questo fatto ha causato due problemi: il primo meramente finanziario, ma pesantissimo, per la corresponsione di TFR e accordo economico di uscita al dipendente, il secondo con l'incognita della scelta della società di segreteria esterna, concretizzata in MV Congressi. Le assicurazioni di un passaggio di consegne indolore, come da mie scettiche previsioni, sono state ampiamente disattese e la nuova segreteria ha cominciato a essere parzialmente operativa a giugno e comincia ora a essere nella piena efficienza. D'altronde la nostra Società non è affatto semplice da gestire globalmente e ha abitudini e meccanismi consolidati che non sono facilmente adattabili a una nuova gestione molto diversa dalla precedente, ma ci stiamo riuscendo. Questa situazione ha però causato forti inefficienze e ritardi che hanno obbligato l'esecutivo a un pesante, quanto inevitabile, sforzo operativo per risolvere le continue emergenze, senza tuttavia ottenere completamente i risultati attesi. Ce ne scusiamo con voi.

In questo scenario, complici il congresso internazionale 2022, costoso per sua natura, con una partecipazione inferiore alle previsioni e il forte innalzamento dei costi, in particolare per la ristorazione, si è inserita, per la prima volta nella storia della SIE, la pesante passività di bilancio 2022 di €. 92.564. La conseguente riduzione delle risorse finanziarie legata a questi due fattori ha condizionato l'operatività della Società nell'anno trascorso. Insieme con il Consiglio Direttivo e i nostri consulenti abbiamo applicato nel 2023 le necessarie contromisure che hanno permesso alla nostra Società di tornare in attivo nel bilancio 2023. È un risultato che va sinceramente al di là delle nostre aspettative e speranze, ma il grande lavoro e le fatiche affrontate ci permetteranno di affrontare con maggiore serenità il 2024 e di raccogliere i risultati dei cambiamenti messi in cantiere.
Tutte queste difficoltà sono però controbilanciate da grandi soddisfazioni legate al nostro **reale campo di azione**, quello **scientifico e culturale.**
Nel mio programma era previsto un ritorno sul territorio della SIE e, grazie al nostro Coordinatore Culturale Davide Castro, ai responsabili di Macro Area Lucia Reggio, Chiara Pirani, Alessandra D'Agostino, Massimo Calapaj e a tutti Soci Attivi referenti regionali, nel 2023 **sono fioriti tantissimi eventi locali** che hanno visto partecipazione numerosa dei Colleghi e risultati in termini di qualità formativa. La strada intrapresa, sulla quale proseguiremo nel 2024 e 2025, è quella giusta per riportare l'attenzione sulla SIE e aumentare il numero di partecipanti ai nostri eventi nazionali.
In tutto questo ci ha aiutati moltissimo la Commissione Comunicazione, coordinata da Andrea Polesel, insieme con nuove sinergie di comunicazione e collaborazioni, non onerose, con importanti gruppi editoriali e media che continueranno nell'anno in corso, anche con l'aiuto di nuovi consulenti che lavoreranno con noi per adeguare l'immagine della SIE e tutta la strategia di comunicazione.
È importante per la SIE che tutti i Soci partecipino alla vita societaria e ai lavori congressuali, se ancora non lo avete fatto iscrivetevi e partecipate, abbiamo tutti bisogno di confrontarci e di imparare! La SIE esiste solo per questo!
Il CD ha lavorato molto sul **Congresso Nazionale 2024**, che quest'anno tornerà a Roma il 14, 15 e 16 novembre. Il tema generale sarà **l'Endodonzia vista attraverso la multidisciplinarietà.** Abbiamo invitato alcuni relatori importanti di altre specialità che ci offriranno un punto di vista diverso, ma convergente, con un'ottica attuale di integrazione polispecialistica. Cambia volto anche il classico corso pre congresso, che quest'anno sarà sostituito da numerosi e interessanti corsi teorico-pratici monotematici, ciascuno con un numero limitato di partecipanti, che si svolgeranno a rotazione nel pomeriggio

di giovedì. La maggior parte di questi corsi saranno targati SIE, con relatori invitati e scelta del tema, ma anche i nostri sponsor principali avranno la possibilità di organizzare alcuni corsi "aziendali" per aggiornarci sui loro strumenti e materiali. Naturalmente del programma faranno parte anche i Premi SIE, le comunicazioni libere, le tavole cliniche, i corsi per le assistenti e tanto altro. Vi ricordo che quest'anno sarà anche un anno elettorale per il rinnovo degli organi societari. Il **Closed Meeting 2024** si svolgerà a Torino il 14 e 15 giugno e, anche qui, abbiamo introdotto cambiamenti importanti. Il venerdì sarà dedicato come di consueto ai lavori societari del Consiglio Direttivo, delle Commissioni di lavoro e, naturalmente, all'Assemblea dei Soci Attivi dove si discuterà della strada che la SIE vorrà tracciare per i prossimi anni. L'**evento sociale**, aperto anche alle famiglie dei Soci Attivi, quest'anno si svolgerà il venerdì sera all'interno dell'affascinante **Museo Egizio di Torino**, il secondo al mondo dopo quello del Cairo per importanza. Ci sarà una visita privata al museo, chiuso al pubblico ordinario, in piccoli gruppi guidati ciascuno da un egittologo e terminerà con una cena organizzata nelle sale museali. Un evento davvero particolare! Ovviamente abbiamo un numero limitato di partecipanti, ma sufficiente ad accoglierci. L'organizzazione di un evento di questa portata necessita di un'attenta organizzazione, proprio per le regole imposte dal Museo Egizio, quindi vi prego di dare la Vostra adesione il prima possibile, seguendo le indicazioni che saranno comunicate. Il sabato mattina, nel particolare ambiente della **Nuvola Lavazza**, si svolgerà la sessione scientifica del Closed Meeting. In un impegno di apertura e condivisione della SIE l'evento sarà aperto a tutti, con pre iscrizione obbligatoria. Sarà un'occasione per la SIE per incontrare i Colleghi che non si occupano specificamente di Endodonzia e per tutti un'opportunità di crescita e di scambio di idee. Parleremo di **traumatologia, riassorbimenti radicolari, gestione della polpa vitale e pedodonzia.** Alla fine dei lavori, o durante la mattinata per i familiari, sarà possibile visitare il Museo Lavazza che è veramente innovativo nei suoi allestimenti.

La SIE partecipa attivamente ai lavori di **ASSO** (Associazione Società Scientifiche Odontoiatriche) intrattenendo rapporti di collaborazione e stima reciproca con le società consorelle. Molto di questo lavoro passa quasi inosservato perché si svolge a un livello di politica della professione odontoiatrica in generale, ma le ricadute saranno significative per noi tutti. L'aspetto visibile di questo lavoro ha, per esempio, riguardato una campagna social contro le fake news in odontoiatria condivisa da tutte le società scientifiche ASSO. Alcuni Soci hanno criticato l'apparente "cattivo gusto" di alcune immagini della campagna che però era stata ideata da una società di comunicazione con il preciso scopo di essere aggressiva e provocante per i pazienti. A gennaio scorso ha avuto luogo il rinnovo del Consiglio Direttivo di Asso. Cristian Coraini, che nell'ultimo mandato ha svolto ottimamente il ruolo di Tesoriere, ha deciso di non ricandidarsi. Tutti noi lo ringraziamo per l'importante e faticoso lavoro svolto in un contesto non facile, ma certamente apprezzato da tutti. Katia Greco è stata eletta nuovo membro del Consiglio Direttivo ASSO.

Il **GIE Giornale Italiano di Endodonzia**, che ha finalmente ottenuto l'**Impact Factor** entrando di fatto in un gruppo ristretto di riviste scientifiche prestigiose sia livello internazionale sia, soprattutto, a livello italiano, da quest'anno passerà a **tre numeri annuali**. Questo fiore all'occhiello della SIE è il frutto del lavoro di anni di tanti Soci e Consigli Direttivi che è impossibile nominare integralmente, ma, a nome di tutti noi, devo ringraziare in particolare il nostro Editor, Sandro Rengo e tutti i suoi più stretti collaboratori. Questo risultato rappresenta un punto di inizio: per far crescere il valore dell'I.F. abbiamo bisogno del vostro aiuto perché, attualmente, solo il 30% dei lavori presentati sono italiani. Invito quindi tutti i Soci a inviare articoli scientifici e, soprattutto, citare altri articoli già pubblicati sul Giornale Italiano di Endodonzia.

La SIE è viva e attiva su molti fronti e, attraverso molti suoi Soci, manifesta a tanti livelli voglia di crescita e cambiamento positivo. Il Consiglio Direttivo e tutte le commissioni di lavoro sono impegnati per ottenere i migliori risultati possibili e accogliere le idee, i consigli e le iniziative di tutti i Soci, ma **il segreto per cambiare e crescere è partecipare!** La Società ha bisogno dei suoi Soci, sottolineare le carenze e le negatività e poi rimanere lontani non può portare alcun frutto, adesso è il momento di sostenere la SIE, partecipare al congresso e agli eventi locali, spingere i giovani a venire da noi per imparare, condividere e cambiare la Società, in meglio!

Vi ringrazio per il tempo e la fiducia che vorrete dedicare alla nostra Società.
Arrivederci al Closed Meeting di Torino!

Mario Lendini

STRUTTURA SOCIETARIA

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SOCI ONORARI

Bresciano Dott. Bartolo
Cavalleri Prof. Giacomo
Pecora Prof. Gabriele
Perrini Dott. Nicola
Vignoletti Dott. Gianfranco

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Altamura Dott. Carlo
Amato Prof. Massimo
Ambu Dott. Emanuele
Amoroso D'Aragona Dott.ssa Eva
Ascione Dott.ssa Maria Rosaria
Autieri Dott. Giorgio
Badino Dott. Mario
Barattolo Dott. Raniero
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Bertani Dott. Pio
Berutti Prof. Elio
Bonaccorso Dott. Antonino Maria
Bonacossa Dott. Lorenzo
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Cabiddu Dott. Mauro
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Cardosi Carrara Dott. Fabrizio
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Carratù Dott.ssa Paola
Carrieri Dott. Giuseppe
Cascone Dott. Andrea
Cassai Dott. Enrico
Castellucci Dott. Arnaldo
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Cavalli Dott. Giovanni
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Cerutti Prof. Antonio
Cerutti Prof.ssa Francesca
Cinelli Dott. Marco
Ciunci Dott. Renato Pasquale
Colla Dott. Marco
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Cortellazzi Dott. Gianluca
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Cozzani Dott.ssa Marina
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D'alessandro Dott. Alfonso
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Del Mastro Dott. Giulio
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Di Giuseppe Dott. Italo
Donati Dott. Paolo
Dorigato Dott.ssa Alessandra
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Fabiani Dott. Cristiano
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Gaffuri Dott. Stefano
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Malentacca Dott. Augusto
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Mancini Dott. Manuele
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Mazzocco Dott. Alberto
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Re Cecconi Prof. Dario
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Santarcangelo Dott. Filippo Sergio
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Sberna Dott.ssa Maria Teresa
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Serra Dott. Stefano
Sforza Dott. Francesco
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Zaccheo Dott. Francesco
Zaccheo Dott. Fabrizio
Zerbinati Dott. Massimo
Zilocchi Dott. Franco

SOCI AGGREGATI

Giannatiempo Dott.ssa Jessica
Ragucci Dott. Gabriele Vincenzo
Rossano Dott.ssa Federica

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Lendini Dott. Mario
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Polesel Dott. Andrea
Revisore dei Conti
Vecchi Dott. Stefano
Revisore dei Conti
Vittoria Dott. Giorgio

SOCI SCOMPARSI

Ricordiamo con affetto e gratitudine i Soci scomparsi:

Attanasio Dott. Salvatore
Socio Attivo
Borsotti Prof. Giancarlo
Socio onorario
Castagnola Prof. Luigi
Socio Onorario
De Fazio Prof. Pietro
Socio Attivo
Dolci Prof. Giovanni
Socio Onorario
Duillo Dott. Sergio
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Garberoglio Dott. Riccardo
Socio Onorario
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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 Segretaria della SIE con un anticipo di 20 giorni sulle date di riunione della CAS, sufficiente per poter organizzare il materiale dei candidati. Le date di scadenza saranno rese note sul sito. La domanda dovrà essere firmata da un Socio Attivo in regola con la quota associativa per l'anno in corso, il quale dovrà aver esaminato e approvato la documentazione. Quest'ultimo è responsabile della correttezza clinica e formale della documentazione presentata.

PRESENTAZIONE DEI CASI ALLA COMMISSIONE

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

LA COMMISSIONE ACCETTAZIONE SOCI

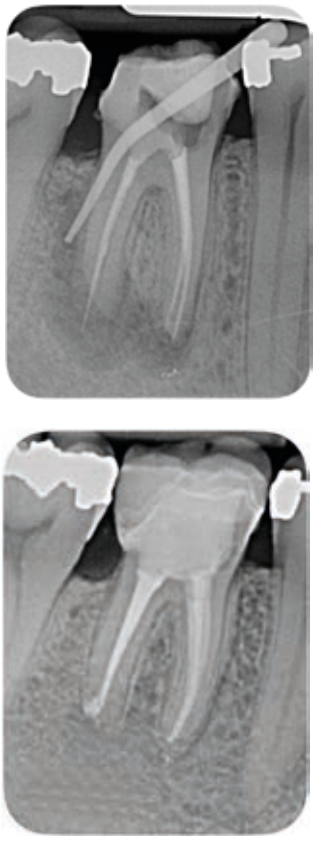
La CAS (Commissione Accettazione Soci) è formata cinque Membri di indiscussa esperienza clinica, quattro Soci Attivi con almeno cinque anni di anzianità in questo ruolo eletti a ogni scadenza elettorale dall'Assemblea dei Soci Attivi e Onorari e uno dei Past President della Società incaricato dal CD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

MEMBRI DELLA COMMISSIONE ACCETTAZIONE SOCI BIENNIO 2023-24

Francesco Riccitiello
Maurizio Boschi
Marco Colla
Claudia Dettori
Giuseppe Multari

CeraSeal

Quality and ergonomics for simple and predictable root canal fillings



Courtesy
of Dott. Filippo Cardinali

Role and aims of root canal obturation

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

Ceraseal: ergonomics and safety

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

Hermetic Seal

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

Flowability and Stability

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

Biocompatibility and Bioactivity

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

sweden & martina

MORITA

New Tri Auto ZX2+

Il nuovo Tri Auto ZX2+ ridefinisce ancora una volta la preparazione endodontica e porta il movimento reciprocante ad un livello superiore. Con la nuova modalità OGP2 e la modalità OTR migliorata, potrete sfruttare appieno il potenziale delle vostre lime preferite, sia reciprocanti che rotanti. La collaudata tecnologia Morita contribuisce a ridurre la rottura e il bloccaggio delle lime, per una preparazione sicura.

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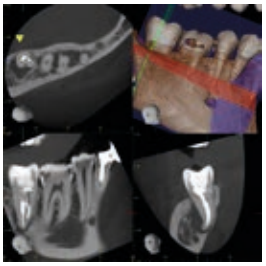

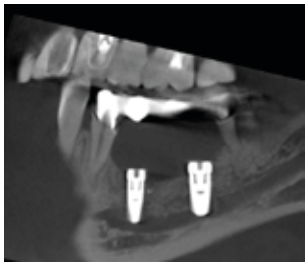

GUIDELINES FOR AUTHORS

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**.

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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.

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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.

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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.

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Manuscript Types Accepted

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

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

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

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

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

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 Systematic Review Articles should be divided into Aim, Methodology, Result, Conclusion.
Aim: Provide an explicit statement of the main objective(s) or question(s) the review addresses.
Methodology: Specify the inclusion and exclusion criteria for the review, the information sources (e.g. databases, registers) used to identify studies and the date when each was last searched. Specify the methods used to assess risk of bias in the included studies and the methods used to present and synthesis of studies.
Results: Give the total number of included studies and participants and summarise relevant characteristics of studies. Present results for main outcomes, preferably indicating the number of included studies and participants for each. If meta-analysis was done, report the summary estimate and confidence/credible interval. If comparing groups, indicate the direction of the effect (i.e. which group is favoured).
Conclusion: Provide a brief summary of the limitations of the evidence included in the review (e.g. study risk of bias, inconsistency and imprecision) and a general interpretation of the results and important implications.

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

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.
Key learning points: provide up to five short, bullet-pointed statements to highlight the key messages of the report. All points must be fully justified by material presented in the report.

THE STRUCTURE

Main text for Original Scientific Articles should include Introduction, Materials and Methods, Results, Discussion and Conclusion.
Introduction: should be focused, outlining the historical or logical origins of the study and gaps in knowledge. Exhaustive literature reviews are not appropriate. It should close with the explicit statement of the specific aims of the investigation, or hypothesis to be tested.

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.
(I) Clinical Trials: should be reported using the CONSORT guidelines available at www.consort-statement.org A CONSORT checklist and flow diagram (as a Figure) should also be included in the submission material.
(II) Experimental Subjects: experimentation involving **human subjects** will only be published if such research has been conducted in full accordance with ethical principles, including the World Medical Association Declaration of Helsinki (version 2008) and the additional requirements, if any, of the country where the research has been carried out. Manuscripts must be accompanied by a statement that the experiments were undertaken with the understanding and written consent of each subject and according to the above mentioned principles. A statement regarding the fact that the study has been independently reviewed and approved by an ethical board should also be included. Editors reserve the right to reject papers if there are doubts as to whether appropriate procedures have been used. When **experimental animals** are used the methods section must clearly indicate that adequate measures were taken to minimize pain or discomfort. Experiments should be carried out in accordance with the Guidelines laid down by the National Institute of Health (NIH) in the USA regarding the care and use of animals for experimental procedures or with the European Communities Council Directive of 24 November 1986 (86/609/EEC) and in accordance with local laws and regulations. All studies using human or animal subjects should include an explicit statement in the Material and Methods section identifying the review and ethics committee approval for each study, if applicable. Editors reserve the right to reject papers if there is doubt as to whether appropriate procedures have been used.
(III) Suppliers of materials should be named and their location (Company, town/city, state, country) included.
Results should present the observations with minimal reference to earlier literature or to possible interpretations. Data should not be duplicated in Tables and Figures.
Discussion may usefully start with a brief summary of the major findings, but repetition of parts of the abstract or of the results section should be avoided. The Discussion section should progress with a review of the methodology before discussing the results in light of previous work in the field. The Discussion should end with a brief conclusion and a comment on the potential clinical relevance of the findings. Statements and interpretation of the data should be appropriately supported by original references.
Conclusions should contain a summary of the findings.

Main Text of Systematic Review Articles
should be divided into Introduction, Methodology, Results, Discussion, Conclusion.
In the case of systematic reviews, whether with or without meta-analyses, strict adherence to the PRISMA guidelines (http://www.prisma-statement.org/) is mandatory. Additionally, authors must submit a PRISMA checklist (http://www.prisma-statement.org/PRISMAStatement/Checklist.aspx) and flowchart (http://www.prisma-statement.org/PRISMAStatement/FlowDiagram) along with the manuscript.

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

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

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

IMPORTANT TO KNOW

Manuscript that do not conform to the general aims and scope of the Journal will be returned immediately without review. All other manuscripts will be reviewed by experts in the field (generally two referees). Giornale Italiano di Endodonzia aims to forward referees´ comments and to inform the corresponding author of the result of the review process. Manuscripts will be considered for fast-track publication under special circumstances after consultation with the Editor.
Our journal uses **single-blind review**: the reviewers know the names of the authors, but the authors do not know who reviewed their manuscript.
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Acknowledgements. Giornale Italiano di Endodonzia requires that all sources of institutional, private and corporate financial support for the work within the manuscript must be fully acknowledged, and any potential conflicts of interest noted. Grant or contribution numbers may be acknowledged, and principal grant holders should be listed. Acknowledgments should be brief and should not include thanks to anonymous referees and editors. Under this section please specify contributors to the article other than the authors accredited. Please also include specifications of the source of funding for the study.

References
It is the policy of the Journal to encourage reference to the original papers rather than to literature reviews. Authors should therefore keep citations of reviews to the absolute minimum. Names of products and/or companies should not be added to references. To cite a product and/or company add the same inthe text, where mentioned.
References should be prepared according to the **Vancouver style**. References must be numbered consecutively in the order in which they are first cited in the text (not alphabetical order), and they must be identified in the text by Arabic numerals in brackets [example (34)]. References to personal communications and unpublished data should be incorporated in the text and not placed under the numbered references [Example: (Wright 2011, unpublished data) or (Wright 2011, personal communication)]. Where available, URLs for the references should be provided directly within the MS-Word document.

References in the References section must be prepared as follows:

I. more than three authors cite 3 authors et al. If the paper has only 4 authors, cite all authors;
   e.g. *Prati G, Lotti M, Russo F et al.*
II. title style: please use a capital letter only for the first word of the title;
III. journal titles mentioned in the References list should be abbreviated according to the following websites:
a. ISI Journal Abbreviations Index (https://www.library.caltech.edu/journal-title-abbreviations);
b. Biological Journals and Abbreviations (http://home.ncifcrf.gov/research/bja);
c. Medline List of Journal Titles (https://www.nlm.nih.gov/bsd/serfile_addedinfo.html);
IV. put year after the journal name;
V. never put month and day in the last part of the references;
VI. cite only the volume (not the issue in brackets);
VII. pages have to be abbreviated, e.g. 351-8.

We recommend the use of a tool such as EndNote or Reference Manager for reference management and formatting. EndNote reference styles can be searched for here: http://www.endnote.com/support/enstyles.asp. To ensure the correct citation format, please check your references in the PubMed database (http://www.ncbi.nlm.nih.gov/pubmed).

Examples of correct forms of reference follow.
Standard journal article
(1) Somma F, Cammarota G, Plotino G, Grande NM, Pameijer CH. The effectiveness of manual and mechanical instrumentation for the retreatment of three different root canal filling materials. J Endod 2008;34:466-9.

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.

URLs
Full reference details must be given along with the URL, i.e. authorship, year, title of document/report and URL. If this information is not available, the reference should be removed and only the web address cited in the text.

Tables, Figures and Figure Legends

Tables should be submitted as word or excel format, numbered and cited in the text of the manuscript. Units of measurements must be included in the column title or in the figure legend or caption.

Figure files accepted: TIF, EPS, JPEG.

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ii) drafting the article or revising it critically for important intellectual content;
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These three conditions must all be met. Participation solely in the acquisition of funding or the collection of data does not justify authorship. General supervision of the research group is not sufficient for authorship. Any part of an article critical to its main conclusions must be the responsibility of at least one author. Authors should provide a brief description of their individual contributions.

Obligation to Register Clinical Trials

http://www.icmje.org/#clin_trials

The ICMJE believes that it is important to foster a comprehensive, publicly available database of clinical trials.

The ICMJE defines a clinical trial as any research project that prospectively assigns human subjects to intervention or concurrent comparison or control groups to study the cause-and-effect relationship between a medical intervention and a health outcome. Medical interventions include drugs, surgical procedures, devices, behavioral treatments, process-ofcare e changes, etc.

Our journals require, as a condition of consideration for publication, registration in a public trials registry.

The journal considers a trial for publication only if it has been registered before the enrollment of the first patient.

The journal does not advocate one particular registry, but requires authors to register their trial in a registry that meets several criteria. The registry must be accessible to the public at no charge. It must be open to all prospective registrants and managed by a non-profit organization.

There must be a mechanism to ensure the validity of the registration data, and the registry should be electronically searchable. An acceptable registry must include a minimum of data elements.

For example http://www.clinicaltrials.gov, sponsored by the United States National Library of Medicine, meets these requirements.

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When reporting experiments on human subjects, authors should indicate whether the procedures followed were in accordance with the ethical standards of the responsible committee on human experimentation (institutional and national) and with the Helsinki Declaration of 1975, as revised in 2013 (https://www.wma.net/policies-post/wma-declaration-of-helsinki-ethical-principles-for-medical-research-involving-human-subjects). If doubt exists whether the research was conducted in accordance with the Helsinki Declaration, the authors must explain the rationale for their approach and demonstrate that the institutional review body explicitly approved the doubtful aspects of the study. When reporting experiments on animals, authors should indicate whether institutional and national standards for the care and use of laboratory animals were followed. Further guidance on animal research ethics is available from the World Medical Association and from the International Association of Veterinary Editors' Consensus Author Guidelines on Animal Ethics and Welfare.

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When receiving a new submission, the Managing Editor assigns it to her/himself and to the Editor-in-Chief (EiC). After a quick in-house evaluation, if the EiC thinks that the paper is compliant with the guidelines and fits with the scope of the Journal, he/she send it out for the **peer-review phase** (=he/she assigns reviewers). If the EiC thinks that the paper is *not* compliant with the guidelines and *does not* fit with the scope of the Journal, he/she notifes via email that the article has been declined.

Once the review process is completed (*i.e.* all the assigned Reviewers have provided their comments and recommendations on the paper), the authors will be notified via

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Depending on the editorial decision, and basing on the reviewers' comments, authors are required to upload their revised version (+ covering letter) within a specific deadline. At this point, they simply need to wait to hear back from the editor as to whether the revisions are acceptable.
If the editor's decision is to resubmit for review (=Major revisions or Minor revisons), the revised paper may undergo a "second round" of peer-review.
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Lastly, once the copyedits are completed and approved, the submission moves to "Production stage". In Production, the copyedited files are converted to galleys (PDF). The authors have the opportunity to proofread the galleys.
Once everyone is satisfied, the article is published in Early Access section of the Journal and scheduled for publication in the available issue (March, July, November).
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All manuscripts submitted to our journal are critically assessed by external and/or in-house experts in accordance with the principles of peer review (http://www.icmje.org/#peer), which is fundamental to the scientific publication process and the dissemination of sound science. Each paper is first assigned by the Editors to an appropriate Associate Editor who has knowledge of the field discussed in the manuscript. The first step of manuscript selection takes place entirely in-house and has two major objectives: i) to establish the article appropriateness for our journals readership; ii) to define the manuscript priority ranking relative to other manuscripts under consideration, since the number of papers that the journal receives is much greater than it can publish. If a manuscript does not receive a sufficiently high priority score to warrant publication, the editors will proceed to a quick rejection. The remaining articles are reviewed by at least two different external referees (second step or classical peer review). Manuscripts should be prepared according to the Uniform Requirements established by the International Committee of Medical Journal Editors (ICMJE) (http://www.icmje.org/org/#prepare).