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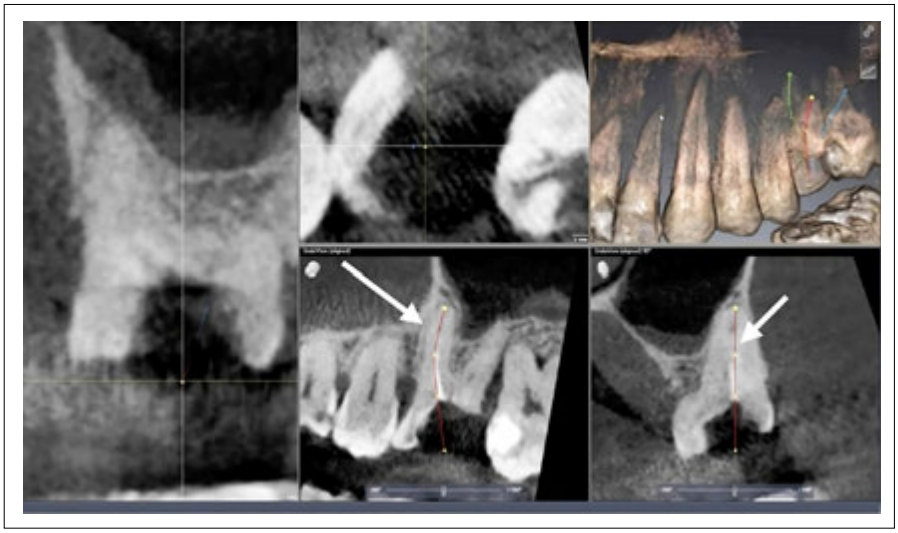

▸ Original articles

Influence of smoking habit in the incidence, intensity and evolution of post-operative pain during the week after root canal treatment

Evaluation of the effect of cetrimide associated with photodynamic therapy in reducing Enterococcus faecalis from the root canal system.

In vitro comparative efficacy of two pulse widths of SWEEPS for elimination of Enterococcus faecalis biofilm from the root canals

Comparative analysis of debris extrusion and instrumentation time among various endodontic file systems: an in vitro study

▸ Case Report

Successful treatment of a damaged upper molar using 3D Technology, a case report with 4 years follow-up

Late re-implantation (48 hours) of an avulsed upper central incisor to preserve function, esthetics and alveolar bone for eleven years.

▸ Systematic Review

The treatment options for the management of internal root resorption

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Table OF CONTENTS

7 **Editorial**

Endodontics: the central core within a multidisciplinary approach
Sandro Rengo

8 **Original articles**

Assessment of factors influencing post-operative pain: the impact of smoking habit in root canal treatments obturated with carrier-based technique and epoxy resin sealer
Chiara Pirani, Francesco Iacono, Carlo Prati, Ana Arias*

17 The effect of the combination of cetrimide and photodynamic therapy in reducing *Enterococcus faecalis* load from the root canal system
Andrea Viana Vidal, Carlos Eduardo da Silveira Bueno, Alexandre Sigrist De Martin, Rina Andrea Pelegrine, Carlos Eduardo Fontana, Daniel Guimarães Pedro Rocha, Wayne Martins Nascimento, Ana Graìsiela Limoeiro, Marilia Fagury Videira Marceliano-Alves, Sergio Luiz Pinheiro*

25 In vitro comparative efficacy of two pulse widths of SWEEPS for elimination of *Enterococcus faecalis* biofilm from the root canals
*Mahta Fazlyab, Niknaz Jahedmanesh, Yashar Safaraei, Luca Solimei, Stefano Benedicenti, Nasim Chiniforush**

32 YouTube™ as a supplemental learning source for undergraduate dental students
Giovanni Mergoni, Benedetta Ghezzi, Andrea Salvaterra Toffoli, Maddalena Manfredi*

43 Comparative analysis of debris extrusion and instrumentation time among various endodontic file systems: an in vitro study
Carlos Eduardo Fontana, Beatriz dos Santos Ribeiro, Luana de Carvalho Davanso, João Daniel Mendonça de Moura, Daniel Guimarães Pedro Rocha, Rina Andrea Pelegrine, Carlos Eduardo da Silveira Bueno, Sérgio Luiz Pinheir*

Table OF CONTENTS

54 A comparison in the efficacy of 3D-printed guides versus traditional endodontic access: an ex-vivo study

*Alvaro Garcia-Sanchez, Manuel Sato, Angelica Gargano, Myra Nasir, Afroditi Pita, Maria-Victoria Mateos-Moreno, Alba Pérez-Jardón, Ángel-Orion Salgado-Peralvo**

64 **Systematic Review**

The treatment options for the management of internal root resorption

Ruta Prialgauskė, Greta Lodienė, Ana Kostenkova, Neringa Skučaitė*

81 **Case report**

Late re-implantation (48 hours) of an avulsed upper central incisor to preserve function, esthetics and alveolar bone for eleven years

Norberto Broon, Alvaro Cruz, Gerardo Gascón, Itzel Estefania Hernández-Meza, Clovis Monteiro Bramante*

91 Successful treatment of a damaged upper molar using 3D Technology: a case report with 4 years follow-up

Bogdan Oprea, Maria Mihaela Iuga, Fernando M. Espada Salgado, Kavalipurapu Venkata Teja, Artur Grila, Dan Herschbach, Bianca Oprea, Michele Simeone*

Vita Societaria

101 Lettera del Presidente

Editorial

Endodontics: the central core within a multidisciplinary approach

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The 39th National Congress of the Italian Society of Endodontics (SIE) will open very soon, and, after long time, it'll take place in Rome. The crucial appointment within the social year – from 14 to 16 of Novembre 2024 – is even renewed about the cultural program that includes the presence of several branches of dentistry, as suggested by the event's title "Le Fondamenta della Multidisciplinarietà: 5 Discipline, 18 Relatori, da Dove Partire?" – "The basis of multidisciplinarity: 5 disciplines, 18 lecturers, where to start?" Endodontics will represent the central core within a multidisciplinary approach, that involves different subjects and several specialists. During the congress, transversal topics will be developed such as enrichment of traditional techniques and introduction of innovative and mini-invasive approaches, with particular attention to the maintenance of tooth vitality and masticatory function over time.

The importance "to keep" rather than "to replace", has again highlighted the centrality of endodontics and its fundamental role within wider treatment plans. The same trend is observed in the present issue of Giornale Italiano di Endodonzia in which different topics are developed as prost-operative pain, root canal decontamination, mechanical instrumentation, trauma management and post-endodontic reconstructions. Moreover, two papers regarding the use of 3D technology in endodontics are included, describing a current topic that might be very interesting for the scientific community.

The tridimensional planning of endodontic treatment, both surgical or not, provides a valid contribution to the respect of anatomical structures, to the design and execution of access cavity and to the rehabilitation of masticatory function in case of extremely damaged dental elements, resulting in a decrease of operator-dependent issue and enhancement of treatment predictability. The preservation of health tissue as well as the pre-operative planning of complex therapies – as removing of intra-canal calcifications, removing of intracanal posts and endodontic retreatments – would determine a substantial contribute to the increase of therapeutical success over time. The extensive study of these topics will allow to train even more expert and conscious clinicians. Indeed, undergraduate students' education is the objective of a study included in the present issue that suggests an innovative and unusual approach, strengthening the relevance of teaching in the growth of future endodontists.

See you in Rome,
Sandro Rengo

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ORIGINAL ARTICLE

Assessment of factors influencing post-operative pain: the impact of smoking habit in root canal treatments obturated with carrier-based technique and epoxy resin sealer

ABSTRACT

Aim: *To confirm predictive factors of post-operative pain (PP) and to further explore if smoking habit may influence the incidence, intensity and evolution of PP.*
Methodology: *Two hundred forty-five consecutive patients requiring endodontic treatment were included and pre-operative, patient and tooth-related factors were recorded. Patients were divided in 3 categories depending on smoking habit: non-smokers/light-smokers (<10 cigarettes/day)/heavy-smokers (³10 cigarettes/day). Questionnaires recorded presence and intensity of post-instrumentation (PIP) and post-obturation pain (POP) in a 100 mm Visual Analogue Scale (VAS) at 24,48,72 hours (h), 7 days (d). Linear regression analysis determined the patient-, tooth- and treatment-related factors influencing intensity of PIP and POP at 24, 48, 72h, 7d after treatment. Logistic regression was used to assess variables influencing incidence of PP and need of painkillers. Linear-by-linear association test was used to assess differences in trend of intensity of PP among non-, light- and heavy-smokers at different time points.*
Results: *Two hundred twenty-three patients returned the questionaries. Incidence and intensity of POP were influenced by: patient-related (smoking habit, gender), tooth-related (endodontic status, size of periapical lesions), treatment-related factors (obturation quality). Heavy-smokers showed significantly higher incidence of POP ($p<0.03$) both 24 and 48h after treatment (OR=4.33, 95% CI 1.13-16.58 and OR=6.22, 95% CI 1.14-27.36 respectively). Different factors affected incidence and intensity of PIP/POP. Heavy-smokers had a higher incidence of PP than light and non-smokers. Smoking habit influenced intensity of POP during the first 48h after treatment.*
Conclusions: *Heavy smoking habit can adversely influence the intensity of post-obturation pain during the first hours after root canal treatment.*

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KEYWORDS *Heavy smoker, postoperative pain, prospective clinical study, root canal treatment, smoking habit*

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Introduction

In Endodontics, the onset of pain and/or swelling after root canal treatment can be very distressing to both the patient and the operator, especially since patients often consider post-operative pain and flare-up as a benchmark to measure the clinician's skills (1). Post-operative pain is acquiring significance as a fundamental patient-centred outcome affecting quality of life and for this reason, the development of standard guidelines is advocated (2) to provide evidence-based recommendations. Post-operative pain of mild intensity is a common consequence of root canal preparation with a prevalence ranging from 3%-58%, while severe sequelae are rare but represent an emergency (1). The aetiology of PP is commonly related to tissues injury of chemical, mechanical or microbiological nature, most commonly due to the apical extrusion of infected debris and irritants (3). This fall-out is caused by many factors related to the experience of the operators and the instruments or techniques utilized, but factors inherent to patients also play an important role on PP occurrence and intensity. In any case, this post-preparation aftermath continues to show a high variability in prevalence among the increasing number of studies published by researchers. This variability can be due to the heterogeneity of inclusion criteria, study methods and intensity of pain taken in consideration.

Smoking behaviour is a multifactorial trait influenced by genetic and environmental components (4), primarily maintained by the positive and negative reinforcing properties of nicotine. It is demonstrated to cause a variety of diseases that can also lead to premature death and a significant reduction in the quality of life. While smoking habit is well known to adversely impact on oral health, by increasing the risk of oral cancer, lesions of the oral mucosa and periodontal disease, its role in endodontics is rarely considered. An association between prevalence of periapical periodontitis and smoking has been hypothesized with controversial conclusions (5, 6) and for this reason clinical studies including an evaluation of smoking habit of the patients are advocated to address this gap in knowledge. To the best of our knowledge, this is the first study to evaluate the influence of smoking habit on the incidence, intensity and evolution of post-operative pain during the week after root canal treatment.

Therefore, the purpose of this prospective clinical study was to evaluate the prevalence of PP following RCT performed by postgraduate master's students in a University Endodontic Department. and to examine whether the smoking habit could be a risk factor contributing to a high recurrence rate of post-operative pain after endodontic treatment.

Material and Methods

This prospective study was conducted with the approval of the Ethical Committee of the University of Bologna (protocol number 0069637). Two hundred and forty-five consecutive subjects with single- or multi-rooted teeth requiring root-canal treatment for prosthetic reasons, irreversible pulpitis, pulp necrosis or failed primary treatment were enrolled in the study and treated between January and October 2018 in full compliance with the World Medical Association Declaration of Helsinki (7).

Sample size calculation was performed using the information derived from a preliminary trial comparing the incidence of post-obturation pain after 24 hours between smoker and non-smoker patients submitted to root canal treatments. Considering a size ratio of 0.3 between smokers and non-smokers, a minimum sample size of 145 non-smoker and 43 smoker subjects was required to detect differences accepting an alpha risk of 0.05 and a beta risk of 0.2 in a two-sided test. Further estimations, anticipating 30% dropouts, suggested a total adjusted sample size of 244.4 patients.

Only those subjects having satisfied the following criteria were included in the study: the subject residing in the country, being 18-70 years old at time of treatment, systemically, healthy, having adequate oral hygiene with Plaque Index ≤20% and the

tooth having pre-operative probing depth of ≤5 mm.

Subjects with the following criteria were excluded from the study: pregnancy, history of medication for chronic pain or with compromised immune response, failure to obtain authorization from patients, presence of difficult root canal anatomy (root canals with extreme curvatures, internal or external resorption or radiographically untraceable canal paths), or any accident or complication occurring during treatment. Patients whose forms were incompletely or inadequately filled out were excluded also.

A preliminary visit was performed to collect clinical and radiological findings. Each involved patient signed an informed consent and accepted to participate to the study. The enrolled clinicians were postgraduates (n=17), operating under the supervision of trained tutors. The same treatment protocol was followed. Demographic and medical information were registered for each patient, pre- and intra-operative data were recorded by a single operator. Among the variables registered, patients were inquired about their smoking habit and number of cigarettes consumed *per* day. Patients were then classified as non-, light- or heavy-smokers depending on the number of cigarettes consumed per day. Non-smokers were defined as subjects who had never smoked at least one cigarette every one to three days, light-smokers were defined as subjects who smoked <10 cigarettes every day in the past year and heavy-smokers were defined as subjects who smoked =>10 cigarettes every day in the past year.

Type and location of treated teeth was also registered. Ethyl chloride (Crio Spray SZ, Karl San Marino) was used to test pulp vitality. In case of negative response, the diagnosis of necrosis was confirmed by the absence of bleeding after opening the pulp chamber. The patient was inquired about the presence of pre-operative pain in the previous 24 hours and pre-operative drug intake. The presence of periapical lesion was assured by the value of Peri-Apical Index (PAI) determined by 2 blinded experienced evaluators following Ørstavik et al. (8) directives and the diameter of the lesion was measured with a calliper. The curvature Radius was also registered, and teeth were classified in 3 groups (straight, moderate or severe).

The RCT was performed using the following protocol: the patient was asked to rinse his mouth with 0.2% chlorhexidine for 60 seconds. Hard and soft tissues were then anesthetised based on the tooth location using mepivacaine (Carboplyina, Molteni, Scandicci, Italy). Rubber dam (Hygenic Dental Dam, Coltène Waledent, Cuyahoga Falls, OH, USA) was applied to isolate the operating field. A high-speed, water-cooled diamond bur (Intensiv, Grancia, Switzerland) was used to gain straight access to the pulp chamber. The interferences were removed using Batt and Gates-Glidden burs (Dentsply Sirona, Ballaigues, Switzerland). A 10 K-file (Dentsply Sirona) was then utilized to scout the root canal and negotiate to the apex. Working Length (WL) was determined using an apex locator (Root ZX, J Morita, USA) and confirmed by an intraoperative radiograph. A manual glide path was then achieved using K-files up to a nominal size #20. Root canal preparation was performed with Hyflex NiTi rotary instruments following manufacturer directions for use (500 rpm rotational speed, 2.5 Ncm torque). Irrigation was performed with 5 to 10 mL of 5% NaOCl solution (Niclor 5, Ogna, Muggiò, Italy) and 1 to 3 mL of 10% EDTA (Tubuliclean, Ogna).

In retreatment cases, removal of previous obturation material was accomplished with size 4-3-2 Gates-Glidden drills and hand files with the use of solvent (Endosolv Septodont, Saint-Maur-des-Fosses Cedex, France). Final preparation was completed as previously described with Hyflex instruments.

A temporary filling with cotton pellets and Coltosol (Coltène-Whaledent, Altstätten, Switzerland) was applied after complete root canal preparation. The presence of occlusal and interproximal contacts was recorded. The patient was then dismissed after receiving post-operative instructions and a first questionnaire to register post-instrumentation pain (PIP) based on a printed Visual Analogue Scale (VAS) (9). Patients were asked to place a mark on the 10-cm line to evaluate the PP severity at 24, 48, 72 hours and 7 days after treatment as described in

a previous study (10). They were also asked to register analgesic intake over time. The results were collected in the second appointment and the treatment obturation of the root canal system completed with AH Plus sealer (Dentsply-DeTrey, Konstanz, Germany) and carrier-based system Thermafil. The patient then received a second questionnaire to register post-obturation pain (POP), to be returned at the next appointment for final restoration.
Hence, intensity of post-operative pain was registered both after instrumentation and obturation appointments using a visual analogue scale (VAS) at 6, 12, 24, 48 h and 7 days after treatment, as well as the need of analgesic intake over time. General pain levels were also recorded as None (0), Mild (1-3), Moderate (4-6) and Severe (7-10), as previously reported (11).

Statistical analysis
A multivariate statistical analysis was used to control any possible confounding factor. A linear regression analysis was used to determine the patient-, tooth- and treatment-related factors that influenced the intensity of post-instrumentation (PIP) and post-obturation pain (POP) 24, 48, 72 hours and 7 days after treatment. A logistic regression was also used to assess the variables that influenced the incidence of post-operative pain and the need of painkillers after both appointments. Odds ratios and their 95% CI were also estimated in the logistic regression analysis to measure the magnitude of the effect and quantify the strength of the association between the significant factors and the event. Beta coefficients and their 95% CI were also calculated in the linear regression models. The linear-by-linear association test was used to assess any difference in the trend of general levels of post-operative pain among non-, light- and heavy-smokers at the different time points.

Results

A total of 223 participants returned the questionnaires properly filled and were included in the statistical analysis. Out of these, 57% were females and 43% males with 18% aged <30 years, 36% 30-50 years and 46% >50 years. Fifty-seven % of them presented pre-operative pain and 43% (49/223) did not. 70% were non-smokers and 30% smokers (156/67). From the smokers, 50.75% were considered light-smokers and 49.25% heavy-smokers.
Different factors affected the incidence and intensity of PIP and POP pain at the different time points.
The endodontic status of teeth influenced both the incidence of PIP 24h and 72h after treatment ($p<0.05$). Patients presenting for a root canal treatment in a vital tooth experienced a significantly higher incidence of PP with an OR=3.96 (95% CI 1.16-13.47) and OR=8.56 (95% CI 1.1-62.2) respectively 24 and 72 hours after treatment. Also, patients with vital teeth showed a significantly higher intensity of PIP (beta coefficient= 1.38; 95% CI 0.24–2.53). No other factors significantly increased the chances of suffering PIP or the intensity at any time point after treatment. On the contrary, both the incidence and intensity of POP were influenced by many factors. Specifically, patient-related factors like smoking habit and gender significantly influenced the chances of experiencing POP during the first days after treatment. Heavy smokers showed a significantly higher incidence of POP ($p<0.03$) both 24 and 48h after treatment with an OR=4.33 (95% CI 1.13-16.58) and OR=6.22 (95% CI 1.14-27.36), respectively. At the same time, the incidence of POP was also higher in women ($p=0.017$) 24 and 72h after treatment with an OR= 2.45 (95% CI 1.18-5.1) and OR= 2.92 (95% CI 1.1-7.71), respectively. Obturation quality greatly affected the chances of suffering POP 24h after treatment ($p=4´10^{-4}$). Unintentional canal overfilling was associated to higher incidence of POP 24h with an OR= 10.1 (95% CI 3.37-30.23). Endodontic status and the size of periapical lesions also significantly affected the presence of POP 48h after treatment. Patients presenting for a root canal treatment in a vital tooth or in a tooth with a large lesion experienced a significantly higher incidence of POP with an OR= 5.36 (95% CI 1.02-28.18) for vital teeth and OR= 4.7 (95% CI 1.18-18.79) for large lesions.

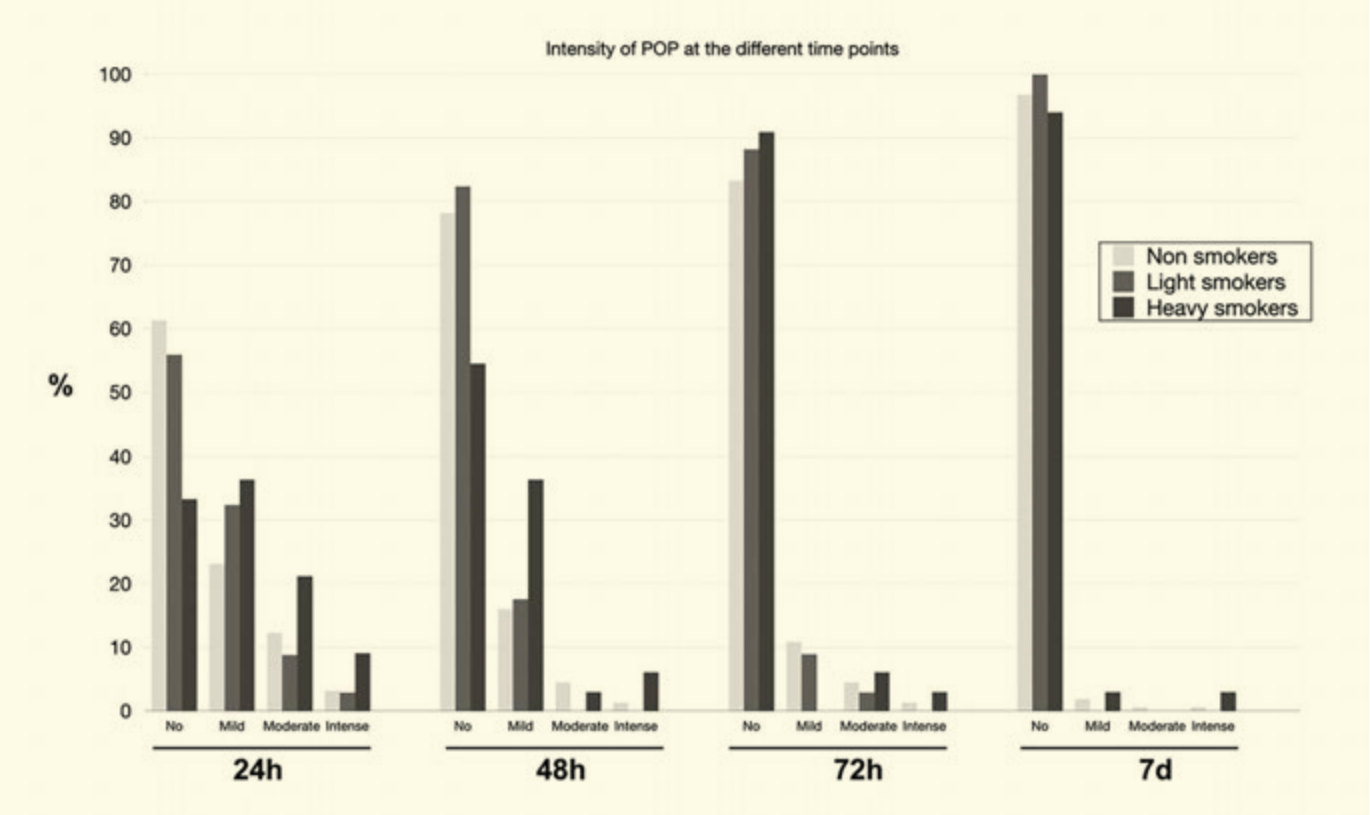

Figure 1.
Intensity of post-obturation pain (POP) at different time points evaluated depending on smoking habit of patients is represented.

In terms of intensity, gender significantly influenced the intensity of POP at all different time points, and both the smoke habit and the size of the periapical lesion did at 24, 48 h after treatment. The presence of unintentional root canal overfilling and the endodontic status also affected the intensity of pain 24h after treatment significantly. Endodontic status and the size of the periapical lesion also influenced the need for medication intake.
Table 1 shows the percentage of participants suffering post-operative pain, as well as mean (and SD) VAS score, at the different time points related to smoking habit. Heavy smokers showed a significant tendency for a higher general intensity of PIP 48 hours (p=0.03) and POP 24 (p=0.006) and 48 h after treatment (p=0.02) than light or non-smokers (Fig. 1).

Discussion

Post-operative pain is one of the most relevant factors that impacts on the patient psychology and tolerance (12). This study was designed to assess those factors influencing post-operative pain after root canal treatments performed in a University Department and, more specifically, to better understand the influence of smoking habits in the incidence, intensity and evolution of post-operative pain in endodontics.
Post-operative pain management is very important in endodontic practice because it joins both patients and clinicians in an unpleasant experience. Thus, its prevention and management are of prime importance (13). Several strategies have been used to evaluate post-operative pain and in the present research the VAS scale was chosen because it has been well validated and extensively used by researchers as a standard outcome (9, 11, 14, 15). Many variables influence the occurrence of post-operative pain and for this reason it is challenging to single out possible causes. In the present study all the included teeth were instrumented with thermally-treated HyFlex NiTi files to avoid variables related to instrumentation. Recently,

Table 1
Descriptive analysis of pre-operative and post-operative variables.

Pre-operative Variables	(N)
Tooth Arch	
Maxilla	126
Mandible	97
Teeth group	
Incisive	30
Canine	7
Premolar	66
Molar	120
Initial PAI	
PAI ≤2	135
PAI ≥3	88
Initial diagnosis	
Pulp exposure	38
Irreversible pulpitis	60
Acute AP	28
Chronic AP	72
Prosthetic reason	25
Post-operative Variables	
Root filling quality	
Underfilled	5
Adequate	184
Overfilling	34
Apical Diameter	
<35	148
35-45	66
≥50	9
Curvature radius	
Staight	108
Moderate	94
Severe	1
Final coronal restoration	
Composite	105
Post	93
Crown	25
Total	**223**

it was reported a lower intensity of PP when retreatment procedures were performed with continuous rotation instead of reciprocation (16). Interestingly, in the current study the incidence of PIP after treatment of teeth with vital pulp was higher, as previously reported (17). It remains fascinating to further investigate the role of extrusion beyond the apex during instrumentation and to correlate the operator-dependent variables. Only teeth treated in multiple visits were herein included to avoid the confounding factors associated with instrumentation and obturation in single visit.

The present study confirmed the influence of several factors in POP pain phenomena. A relation between patient- related factors like gender and incidence of POP was confirmed, observing that female patients experienced a higher level of pain in the short term, as previously reported (18-20). The size of periapical lesion and the endodontic status (vital pulp) also influenced the presence of POP, in accordance with previous findings (21, 22) even if implications are controversial (18). Hence, the increase of pain intensity associated with large periapical lesion and with vital teeth influenced the need for medication intake. The available clinical evidence suggests that the obturation technique with more recent calcium-silicate based sealers provided similar clinical and radiographic results when compared to alternative obturation materials and techniques (23, 24). It remains inconclusive whether premixed bioceramic sealers differ from epoxy resin-based sealers in terms of post-operative pain (24). Moreover, epoxy resin-based sealers are considered a reference material and have been described as the gold standard for sealer cements (25-26). Resin based sealer extrusion does not seem to impair endodontic outcomes, neither in the medium nor in the long term, as previously pointed out (27-30). However, similar to the findings by a prior study (20), an unintentional overfilling of sealer was confirmed to increase the post-operative pain levels and should be therefore carefully avoided during clinical procedures of root canal obturation with carrier-based systems and resin-based sealers.

Increasing attention is given to the role of smoking habit as a risk factor for chronic pain due to the profound changes produced in human physiology (31). Smoking may increase pain sensitivity in general by impairing the delivery of oxygen-rich blood to bones and tissues. Decreasing blood and nutrient flow can cause tissue degeneration. Physicians also link smoking with fatigue and slower healing, factors that make

Table 2

Percentage of participants suffering post instrumentation pain (PIP), and post obturation pain (POP) as well as mean (and standard deviation (SD)) visual analogue score (VAS), at the different time points related to smoking habit.

	Mean VAS (SD) / Percentage of participants suffering PP							
	PIP				POP			
	24h	48h	72h	7d	24h	48h	72h	7d
Non smokers	1.92 (2.3) / 46.8	1.2 (1.9) / 27.6	0.69 (1.4) / 17.3	0.26 (0.9) / 5.1	1.55 (2.1) / 38.7	0.84 (1.5) / 21.8	0.64 (1.3) / 16.7	0.2 (0.7) / 3.1
Light smokers	1.72 (1.6) / 52.9	1.1 (1.5) / 29.4	0.53 (0.9) / 11.8	0.12 (0.5) / 2.9	1.59 (2) / 38.7	0.64 (1) / 17.6	0.52 (1.2) / 11.8	0.03 (0.1) / 0
Heavy smokers	2.73 (2.4) / 63.6	1.74 (2.1) /48.5	0.8 (1.9) / 12.1	0.41 (1.5) / 9.1	2.78 (2.6) / 66.7	1.55 (1.9) / 45.5	0.83 (1.7) / 9.1	0.35 (1.5) / 6

painful conditions more prominent (31). Regarding pulp tissue, a significant increase of levels of neuropeptides such as calcitonin-gene related-peptide (CRGP) has been documented in the pulps from painful teeth of smokers compared with non-smokers (32). Moreover, smokers have a significantly reduced expression of TNF-α, and hBD-2 levels compared with non-smokers, suggesting that dental pulp of smokers possesses limited defence mechanisms against microorganisms (33). Smoking appears to be one of the most significant prognostic factors in the progression of marginal periodontitis (34) and has been previously reported as a statistically significant risk factor for developing apical periodontitis (35). Moreover, despite the paucity of evidence connecting smoking with endodontic disease, a significant association was found between this habit and a reduced chance of periapical bone healing (6, 34, 36, 37). This speculation has also been confirmed by a recent study (38) that found smoking as a significant predictive factor for a worse outcome in endodontics. Even if limitations of the analysis of this research include possible bias, due to the subjectivity of pain perception and to the smaller ratio of smoker patients, an interesting association between smoking habit and post-operative pain intensity was found, identifying smoking as a relevant predictor of pain. Evidence of change in the microbiome of smokers has been also reported (39), potentially leading to shifts in functional pathways with implications for smoking-related diseases. It can be speculated that heavy smokers could have a more aggressive pathogenic bacterial flora and therefore experiencing more PP despite the same extrusion of debris from the apex during endodontic procedures. Although no previous studies commented the relation between smoke factor and post-operative pain, it may be hypothesized from our results that smoking habit plays an important role in the process of pulpal/periapical inflammation and pain, by inducing an increase of perceived pain intensity. These considerations must be confirmed by increasing the number of analysed patients and further investigations on the role of tobacco use on endodontic pain are required.

It might be appropriate for the clinicians to inform a smoking patient that a particular recommendation related to the incidence and resulting management of post-endodontic pain might be applicable, after considering all other circumstances pertinent to that individual.

Conclusions

Within the limitations of this prospective study, present findings suggest a higher incidence of PP associated to heavy smokers, in female patients, after

unintentional overfilling, depending on the periapical lesion size and on the pre-operative pulpal status. There is a need for clinical pain researchers to fulfil these requirements in future trials in order to optimize post-operative pain management recommendations.

Clinical Relevance

Heavy smoking habit can adversely influence the intensity of post-obturation pain during the first hours after root canal treatment.

Conflict of Interest

All authors disclose any potential sources of conflict of interest.

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Ethical approval

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

Informed consent

Informed consent was obtained from all individual participants included in the study.

Compliance with Ethical Standards

Chiara Pirani declares that she has no conflict of interest. Francesco Iacono declares that he has no conflict of interest. Carlo Prati declares that he has no conflict of interest. Ana Arias declares that she has no conflict of interest.

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ORIGINAL ARTICLE

The effect of the combination of cetrimide and photodynamic therapy in reducing *Enterococcus faecalis* load from the root canal system

ABSTRACT

Aim: *To evaluate the effect of cetrimide (CT) in combination with photodynamic therapy (PDT) on the reduction of Enterococcus faecalis in the root canal system.*
Methodology: *Forty mesiobuccal canals from extracted human mandibular molars contaminated with the standard strain of Enterococcus faecalis were selected. Instrumentation was performed using the WaveOne Gold Primary file (25.07) and specimens were randomly divided into two groups (n=20): PDT - 0.01% methylene blue photosensitizer was applied for 5 minutes, PDT was performed with 660 nm, 9 J red laser for 90 seconds with fiber optics; CT + PDT – Cetrimide was placed for 60 seconds, photosensitizer was applied, and PDT was performed as described in the PDT group. Samples were collected before instrumentation and after disinfection procedures for each group. The results were subjected to the Kruskal-Wallis statistical test (Student-Newman-Keuls) with a significance level of 5%.*
Results: *There was a microbial reduction before and after PDT and CT +PDT ($p<0.0001$). The use of CT in conjunction with PDT resulted in a significant increase in microbial reduction compared to the use of PDT alone ($p=0.0226$). There was no significant difference between sample groups in microbial counts performed prior to disinfection protocols ($p=0.5448$).*
Conclusion: *The use of CT in conjunction with PDT proved to be highly effective in allowing deeper penetration of the photosensitizer into the dentinal tubules, thus improving the root canal disinfection process.*

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Introduction

The goal of endodontic treatment is to disinfect the root canal system with the reduction of bacteria and microorganisms (1). Techniques include mechanical debridement and shaping of the root canal system with various systems, intracanal irrigation with antimicrobial agents, and intracanal medication (2). However, eliminating microorganisms from the infected canal is a difficult task due to the complex anatomy with its branches, accessory canals, and isthmuses. With the technological advances in microbiological culture and identification, it is already known that in teeth with pulp necrosis and without endodontic intervention, there is a mixed microbial colonization with gram-positive and gram-negative species, with anaerobes predominating (3). The use of auxiliary methods in the disinfection process of the canal system is necessary, especially in the case of persistent microorganisms (4).

Photodynamic therapy (PDT) has been explored as an aid in root canal disinfection (5-7). The technique is based on the use of photosensitizers (PS) that interact with the target cell and are excited in the presence of visible light of appropriate wavelength (1). In the excited state, called triplet, PS can transfer electrons to molecules in the medium or transfer energy to the oxygen molecule. Both reactions produce reactive oxygen species, free radicals, or singlet oxygen, which cause the death of bacteria by damaging the cytoplasmic membrane or DNA.

Several photosensitizers are available for each type of light source which did not induce any damage to the patient and are safe, and the efficiency of PDT depends on the penetration of the photosensitizer on the microbial cell surface (8). The Methylene blue that was the first phenothiazine dye to be synthesized. It is very effective in inactivating gram-positive and gram-negative endodontic bacteria by diode laser irradiation (9). Toluidine Blue is another photosensitizer, that is a thiazine with a π-conjugated structure and has been shown to absorb light in the 596-665 nm wavelength range (10) and has shown to be a highly effective photosensitizer resulted in a significant reduction (P =0.0001) of the initial values of bacteria loads (11). Other photosensitizers solution is the indocyanine Green, that is a water-soluble fluorophore used in clinical research due to its green fluorescence, emitted when excited by near-infrared light, can be detected using dedicated optical systems without affecting the surgical field view (12). Another possible substance to be used as photosensitizer is the cetrimide, that is a cationic surfactant (quaternary ammonium salt) that is in hygroscopic form. It can reduce surface tension (13) and has antimicrobial activity in aqueous solution. According to Bolfoni et al (14), the addition of cetrimide to a 1% NaOCl solution increased the antibacterial activity to a level like 5% NaOCl. Some studies has also shown that cetrimide has good residual activity compared to some antibacterial solutions (15, 16). Wang et al. (17) stated that one of the explanations for the increase in antibacterial activity of cetrimide on dentin could be that surfactants enhance the penetration of the solutions into the dentin tubules by reducing the surface tension of the solutions. There are no published studies in the literature investigating the effect of cetrimide in combination with PDT to reduce the *Enterococcus faecalis* in the root canal system. The aim of this study was to evaluate the effect of combining cetrimide with photodynamic therapy on reducing *Enterococcus faecalis* in the root canal system. The null hypothesis is that there is no difference in microbial reduction in root canals when cetrimide is used PDT.

Materials and Methods

Forty recently extracted human mandibular first and second molars were collected after approval by the ethics committee of the local dental research center (CAAE: 510555921.5.0000.5374). The inclusion criteria was fully formed roots and foramen, multi-rooted teeth with distinct mesio-vestibular and mesio-lingual canals, mesial canals with moderate curvature between 10° and 20° (18) and root canals with an initial anatomical diameter compatible with

a K#10 file. The exclusion criteria were teeth with previous endodontic treatment, teeth with internal/external apical resorption, teeth with radicular carious lesion, teeth with root cracks visible under the operating microscope and calcified root canals. The tooth integrity was assessed under magnification of 16X (DFV, Valença, Brazil).
Teeth were extracted and preserved in 0.1% thymol solution (Farmarim, Colatina, Brazil). The root surfaces were scraped with a No. 14 periodontal curette (Hu-Friedy, USA) to remove any remaining periodontal ligaments. Prophylaxis was performed with a Robinson brush (Microdont, São Paulo, Brazil), a pumice stone (Asfer, São Caetano do Sul, Brazil), and water. After this step was completed, the teeth were rinsed and stored in distilled water until the time of the study.

Standardization of the samples
All specimens were radiographed in the ortho-radial direction to determine the degree of mesio-vestibular root curvature. Dental crowns were cut at the cementoenamel junction using a double-sided diamond disk (KG Sorensen Ind. e Comércio Ltda. São Paulo, Brazil) to standardize root length to 15 mm and root canals with an initial anatomical diameter compatible with a K#10 file. The distal root was cut and discarded. The cervical-apical dimension of the mesial root was measured with a digital caliper (MTX, Salto de Pirapora, Brazil) and the measurement was transferred to a millimeter ruler (Angelus, Lindóia, Brazil). The apical foramen was sealed with epoxy resin (Araldite, São Paulo, Brazil) and the outer surface of the roots, except for the root canal opening, was sealed with two coats of cosmetic nail polish (Impala, Guarulhos, Brazil).

Preparation of the Enterococcus faecalis suspension
The roots were distributed in 24-well cell culture plates. Standard Enterococcus faecalis strain ACTT 19433 (LAB CENTER Campinas, Brazil) was reactivated at brain-heart infusion (BHI) (Difco- Detroit, USA) and incubated in an incubator with 5% CO2 at 37 °C for 24 hours. The 24-hour culture was grown in a Petri dish containing BHI agar and incubated for 24 hours in an incubator with 5% CO2 at 37 °C. After microbial growth, the culture suspension was prepared in a test tube containing 10 mL of sterile saline (0.9% NaCl) at a concentration compatible with standard 10 of the Mc Farland scale (19) Then, in a sterile test tube, 5 mL of the prepared suspension was mixed with 5 mL of BHI broth to obtain a suspension of the final concentration.

Contamination of teeth with Enterococcus faecalis
To facilitate contamination of specimens, teeth were first instrumented to working length (WL) with manual No. 15, 20, and 25 K files (Dentisply Maillefer) and rinsed with sterile saline. The teeth were sterilized in an autoclave at 121 °C for 15 minutes (20). Twenty microliters of the suspension at the final concentration were introduced into the root canal using a BD 10 mL syringe (Plastipak, Curitiba, Brazil) with a BD 20x0.55 24G injection needle (Injex Indústria Cirúrgica LTDA, Guarulhos, Brazil), and a sterile cotton swab soaked with the Enterococcus faecalis suspension was inserted into each root canal entrance. Absorbent cotton soaked with sterile distilled water was placed in 4 wells of each cell culture plate to ensure room humidity. The lid of the plate was closed and sealed with tape and the set was incubated in an incubator at 37 °C and 5% CO2 for 21 days. Every two days, 20 µL of BHI broth was added to the root canal using a BD 10 mL syringe with a BD 24G injection needle, and cotton moistened in distilled water was replaced in the wells of the plates (21).

Confirmation of contamination
Confirmation of the viability and purity of the microorganisms in the root canals was performed weekly by random sampling on two teeth using a sterile paper cone #25 (Endopoints, Rio de Janeiro, Brazil). The cones were left in the canal for 1 minute, seeded in BHI broth, and incubated for 24 hours in an incubator at 37 °C with 5% CO_2 (22). After growth, smear and gram stain were performed for morphological and staining confirmation of the microorganisms.

Microbiological collection before root canal instrumentation

After 21 days of contamination, samples were collected before root canal instrumentation by inserting a sterile cone of N°. 25 absorbent paper into each sample. The cone was held in the root canal for 1 minute and then transferred to a polypropylene flask (Eppendorf, Hamburg, Germany) containing 1 mL of NaCl 0.9% shaken for 30 seconds in a tubular shaker (Vortex AD 56, Phoenix, Araraquara, Brazil).

Serial dilutions of this suspension were prepared to a concentration of 10^5. Aliquots of 0.1 mL of the suspension and each dilution were seeded onto Petri plates containing BHI agar. The cultured plates were incubated in a 5% CO_2 incubator at 37 °C for 24 hours. Colony-forming units (CFUs) per plate were then counted, and the number of CFUs/mL was calculated.

Biomechanical preparation of the root canals

Instrumentation and irrigation were performed by the same operator, a specialist experienced in the use of the system used in the study. "Before canal preparation, each specimen was fixed used a table bench vise and isolated with a rubber dam to simulate clinical conditions." During instrumentation, a sterile gauze (Cremer, Blumenau, Brazil) soaked in sterile saline (Eurofarma, Itupeva, Brazil) was used to clean the active part of the files and remove the adherent dentin debris. A K#25 file (Dentsply Maillefer, Ballaigues, Switzerland) was inserted into the canal until its tip was visible through the surgical microscope (DFV, Valença, Brazil) at 8x magnification in the apical foramen. From this measurement, 1 mm was subtracted to determine the WL.

All roots were prepared using the same instrument protocol and standardization of canal diameter. The mesiobuccal canals were instrumented using the reciprocating technique (23) with the WaveOne Gold 25.07 file (Dentisply, Maillefer) driven by the endodontic motor (Saevo), alternating with the K#10 file used to maintain foraminal patency. A 5 mL of sterile saline was used at each instrument change or at each 1/3 of the prepared root, so that the total volume per canal was 15 mL. Irrigation was performed using a 5 mL disposable syringe (Injex, São Paulo, Brazil) and an Endo-Eze 27 G irrigation tip (Ultradent, Indaiatuba, Brazil), with in-and-out movements to WL. Simultaneously with the irrigation, the irrigation solution was aspirated from the root canal using a metal cannula positioned at the entrance of the canal and connected to a vacuum pump. All canals were dried with a paper cone.

Classification of the treatment groups

Samples were calculated based on the results of the pilot procedure performed with 10 results from the microbial counts of the sample groups using the ANOVA (one-way) test (G Power 3.1.9.4, Franz Faul, College of Kiel, Germany) with α=0.05 and β=0.80, effect size f=0.9. The minimum number of samples calculated for each group was 20. Roots were randomly distributed (www.random.org.br) to the following groups (n=20) (Figure 1).

PDT: 0.01% methylene blue photosensitizer was placed using endo-eze tips with a lateral exit as an endodontic irrigation needle for 5 minutes as a pre-irradiation period. PDT was performed with a low-intensity laser (Lasersmile Hand) using fiber optics (Lasersmile Hand) with 9 J of energy, a power of 100 mW, and a wavelength of 660 nm por 90 seconds. The spot size was 0.0028 cm^2.

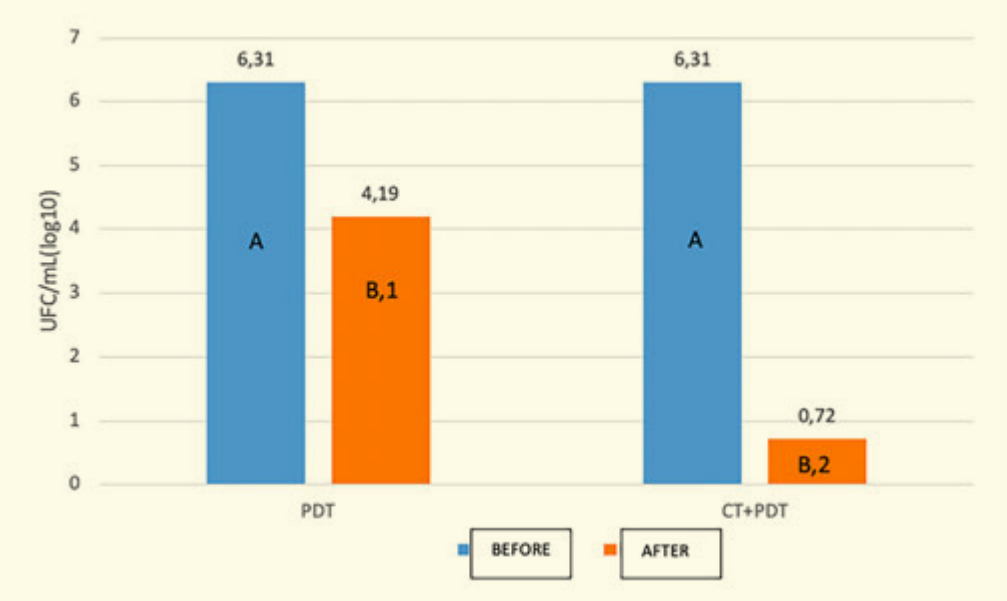
CT+PDT: Before PDT, 2% cetrimide was applied with an irrigation syringe and an endo-eze irrigation tip for 60 seconds. The excess cetrimide was removed with a sterile paper absorbent tip. PDT was then performed as described in the previous group (24).

Sample collection

Samples were collected before instrumentation and after application of PDT and cetrimide+PDT. Samples were collected by inserting a sterile cone of N°. 25 absorbent paper into the root canals. The cone was left in the canal for 1 minute and then transferred to a polypropylene vial containing 1 mL of 0.9% NaCl, which was homogenized on the tube shaker for 30 seconds.

Serial dilutions of this suspension were prepared to a concentration of 10^5. Aliquots

Figure 1
Arithmetic means and Kruskal-Wallis (Student-Newman-Keuls) statistical test for the number of colony-forming units/mL (log10) in the sample groups.



PDT: Photodynamic Therapy; CT+PDT: Cetrimide+Photodynamic Therapy, capital letters and different numbers in horizontal direction: statistically significant differences.

of 0.1 mL of the suspension and each of the dilutions were cultured on Petri dishes containing BHI agar. The colonized plates were incubated in a 5% CO_2 atmosphere at 37 °C for 24 hours. The number of CFU per plate was then counted and the number of CFU/mL was calculated.

Statistical analysis
The results were analyzed using the BioEstat 5.3 program and subjected to the Shapiro-Wilk normality test. The sample showed non-normal behavior. The results were subjected to the Kruskal-Wallis statistical test (Student-Newman-Keuls) with a significance level of 5%.

Results

There was a microbial reduction after PDT and CT+PDT (p<0.0001). The use of CT associated with PDT resulted in a significant increase in microbial reduction compared to performing PDT alone (p=0.0226). There was no significant difference between sample groups in microbial counts performed prior to disinfection protocols (p=0.5448) (Table 1).

Discussion

This *ex vivo* study evaluated the effect of CT associated with PDT to reduce *Enterococcus faecalis* from the root canal system.

Table 1

Medians (MD), interquartile deviations (ID), arithmetic means (MA), standard deviations (SD) and Kruskal-Wallis (Student-Newman-Keuls) statistical test of the colony forming units/mL (log10) counts of the sample groups.

	PDT		CT+PDT		(p-KW)
	before	after	Before	after	
MD(DI)	6.68(0.57)^{A}	4.40(1.18)^{B,1}	6.33(0.71)^{A}	0.00(0.28)^{B,2}	0.0000
MA(DP)	6.31(1.56)	4.19(1.22)	6.31(0.49)	0.72(1.52)	

Legend: PDT: Photodynamic Therapy; CT+PDT: Cetrimide+Photodynamic Therapy, capital letters and numbers different in horizontal direction: statistically significant differences.

The use of CT with PDT resulted in a significant increase in microbial reduction compared with performing PDT alone, so the null hypothesis was rejected. Effective disinfection of the canal is paramount to the success of endodontic treatment (25). *Enterococcus faecalis* is one of the most common microorganisms in necrotic root canal infections (26) and is frequently used in *in vitro* models to evaluate the efficacy of antimicrobial agents (27).

Bacterial biofilms are complex three-dimensional structures formed by a matrix of extracellular polymeric matrix in which bacteria are embedded. For this purpose, several chemical agents are often used that can act on the biofilm, including surfactants. CT has a cytotoxic, bactericidal effect (28), does not irritate host tissues, and has the ability to reduce the surface tension of fluids, which facilitates its penetration into hard-to-reach areas such as the dentinal tubules (29). CT 2% eradicated *S. mutans* in most samples and also increased the rate of biofilm removal (24). In combination with chlorhexidine, it was effective against *Enterococcus faecalis* (30) Another study showed that CT 0.2% had a longer lasting substantivity compared to chlorhexidine 0.2% and almost as long as that of chlorhexidine 2% in a dentin model (31). This could be related to the cationic nature of CT, which is able to interact with dentin. These studies demonstrated the antimicrobial ability of cetrimide and are consistent with the results of the present work, in which the use of CT in conjunction with PDT reduced the load of *Enterococcus faecalis*.

Cetrimide is a cationic surfactant with bactericidal activity and the capacity to decrease the biofilm's mechanical stability (32). Solutions of 2% chlorhexidine and 0.2% cetrimide, when applied for 1 min alone or in final irrigation protocols, can completely inhibit the 24-h *Enterococcus faecalis* biofilm formation in dentin (33), while the combination of 2% chlorhexidine+0.2% cetrimide after the use of chelating agents (34) has been proposed as an effective alternative for final irrigation in root canals because of its antimicrobial action over time.

Although 0.2% cetrimide showed a high residual activity (median: 27 days), a result closer to the one obtained with 2% chlorhexidine had been anticipated, given its greater ability to kill *Enterococcus faecalis* (32) and comparable substantivity determined in a volumetric-dentin unit (35). The present study involved the use of roots where the low surface tension of cetrimide facilitated its diffusion in the main root canal, but the penetration of the solutions into dentinal tubules may be compromised (36). However, it has been shown that the addition of cetrimide in the disinfecting solutions increased their antibacterial effects against *Enterococcus faecalis* in the dentinal tubules (37). In this sense, the results obtained in this study suggest that the antibacterial residual effect of cetrimide would depend on its concentration and the length of its application time (32) or its association with antiseptic agents (35, 36).

PDT is an antimicrobial technique that consists in the application of light to activate a photosensitive agent in the presence of oxygen, generating reactive oxygen species (such as singleto-oxygen) *in situ* and leading to the lysis of bacteria (38). When used in conjunction with chemical-mechanical preparation, PDT has shown a high success rate in primary or secondary infections (39). In this study, an energy of 9 J was used, although PDT cycles above 12 J significantly increased bacterial clearance in another study (40). Alves-Silva et al. (7) demonstrated the efficacy of 0.005% methylene blue followed by red laser irradiation in reducing the total number of bacteria in primary apical periodontitis. Da Silva et al. (41) demonstrated the efficacy of PDT and 0.1% methylene blue in reducing the burden of *Enterococcus faecalis*, *C. albicans*, and bacteria domain. The results are consistent with those of the present study, as PDT was able to significantly reduce the burden of *Enterococcus faecalis*. It is worth noting that penetration of the photosensitizer into the root canal system presents difficulties. The structure of the dentinal tubules, with 1-2 µm lumen and 2-3 mm length, poses challenges to all disinfection methods. PDT is no exception, as light

propagation, and penetration of the photosensitizer into the dentinal tubules is limited (42) The combination of CT with PDT was able to promote deeper penetration of the photosensitizer (methylene blue 0.01%) into the tubules, allowing better disinfection of the root canal. Based on the results of this *ex vivo* study, PDT in combination with CT was 2% more efficient than PDT alone in reducing *Enterococcus faecalis* counts.

The combined protocol using cetrimide and PDT could have some advantages, such as enhancing the antimicrobial efficacy. Cetrimide can disrupt microbial cell membranes, making them more susceptible to the PDT. The cetrimide may help in better penetration of the photosensitizer into microbial cells, increasing the overall effectiveness of PDT (43).

As an *ex vivo* study, it has limitations: the study utilized *an ex vivo* model using extracted human teeth, which may not fully represent the complex biological environment of an *in vivo* root canal system. To validate the findings, further research should be conducted using in vivo models to assess the effectiveness of CT in combination with PDT in real clinical scenarios. It could be concluded that the use of CT in conjunction with PDT resulted in increased microbial reduction and may provide an alternative for disinfection of the root canal system.

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ORIGINAL ARTICLE

In vitro comparative efficacy of two pulse widths of SWEEPS for elimination of *Enterococcus faecalis* biofilm from the root canals

ABSTRACT

Aim: *This study aimed to compare the efficacy of two pulse widths of the shock wave enhanced emission photoacoustic streaming (SWEEPS) for elimination of Enterococcus faecalis (E. faecalis) biofilm from the root canals.*

Materials and Methods: *This in vitro experimental study was conducted on single-rooted single-canal extracted teeth. After cleaning and shaping and sterilization of root canals, they were inoculated with E. faecalis and were randomly assigned to 4 experimental groups (n=8) of (I) SWEEPS with ultra-short pulse (USP) mode and sodium hypochlorite (NaOCl) irrigation, (II) SWEEPS with super-short pulse (SSP) mode and NaOCl irrigation, (III) SWEEPS with USP mode and saline irrigation, and (IV) SWEEPS with SSP mode and saline irrigation, and 3 control groups (n=2) of bacterial inoculation with no disinfection (positive control), bacterial inoculation and disinfection without laser irradiation (negative control), and sterilization alone with no bacterial inoculation. Dentin chips were collected from the root canal walls, and E. faecalis colonies were counted after culture, and statistically analyzed by the Kruskal-Wallis and Dunnett tests (alpha=0.05).*

Results: *All experimental groups showed significantly lower colony count than the positive control group (P<0.05). Among the experimental groups, the highest reduction in colony count occurred in the USP-NaOCl, followed by the USP-saline, with no significant difference with the negative control group. The smallest reduction in colony count occurred in the SSP-saline group.*

Conclusion: *SWEEPS with the USP mode combined with NaOCl irrigation was effective for elimination of E. faecalis biofilm from the extracted root canals.*

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Introduction

Maximum elimination of bacteria from the root canal system is a major prerequisite for a successful root canal treatment. It has been well confirmed that microorganisms remaining in the root canal system are the main cause of endodontic treatment failure and endodontic infections (1, 2). Elimination of bacteria in organized biofilms adhering to the canal walls or those lodged in isthmi, accessory canals, and dentinal tubules is challenging (3). Different bacterial species such as *Enterococcus faecalis (E. faecalis)* are capable of resisting conventional syringe irrigation (CSI) and remain attached to dentin and penetrate deep into dentinal tubules. *E. faecalis* can penetrate into dentinal tubules by 800 µm due to its small size and form intra-radicular and extra-radicular biofilm. It is also resistant to pH alterations (4). In root canals with inflamed or necrotic pulp, bacterial biofilm is often found as a sessile and dense mass in the extracellular matrix, further enhancing bacterial resistance to disinfectants and mechanical debridement, compared with the planktonic form of bacteria. Evidence shows that mechanical root canal instrumentation disinfects only 50% to 75% of the canals at the end of the first treatment session. Although chemical disinfection of the root canals further improves the quality of disinfection, chemical agents still have difficulties in accessing the apical ramifications, isthmi, and accessory canals (5). It has been demonstrated that the penetration depth of sodium hypochlorite (NaOCl), which is commonly used for root canal irrigation, into dentinal tubules is 60 to 150 µm while *E. faecalis* can colonize the dentinal tubules by 600 to 1000 µm depth; other commonly used irrigants cannot penetrate deeper than 100 µm into dentinal tubules (6). The efficiency of root canal disinfection depends not only on the type of irrigant but also on its method of delivery into the canal and its activation (7). The commonly used root canal irrigation techniques include the CSI, passive ultrasonic irrigation, and laser-activated irrigation (LAI). In the CSI, the irrigant does not penetrate into the canals by more than 2 mm; therefore, the irrigant does not often reach the apical region and cannot penetrate into the dentinal tubules (8, 9). In the recent years, the efficacy of laser for activation of irrigants and its role in improving the quality of debridement of the canal walls have been interesting research topics (10). Currently, two methods are available for LAI of the root canals. In the first method, the fiber tip is inserted into the canal, is activated inside the canal and in the irrigating solution, and is subsequently removed slowly; alternatively, it may remain still in the canal or moved within a short distance inside the canal. This technique is known as LAI, which was first introduced with erbium, chromium:YSGG laser, and is commercially available under the brand name of Waterlase. In the second method, the fiber is used outside the canal, and is activated in the irrigant in the pulp chamber above the orifice. This technique was first introduced as photon-induced photoacoustic streaming (PIPS) and used Er:YAG laser. It is commercially available under the brand name of Light Walker Fotona (9, 11). Later on the PIPS technique was replaced with a newer technique known as the shock wave enhanced emission photoacoustic streaming (SWEEPS). In the PIPS technique, one single laser pulse is irradiated in the solution, and after its absorption by the solution, a vapor bubble forms at the end of the laser tip, which expands and bursts. In the SWEEPS technique, simultaneous and fast bursting of the formed bubbles creates a supersonic turbulent stream of irrigant. Also, the device tips used for PIPS and SWEEPS are different (12, 13). Ozkaya et al. (10) compared the efficacy of PIPS, Nd:YAG laser, and CSI for elimination of *E. faecalis* biofilm and reported significantly higher antibacterial and anti-biofilm effects of Er:YAG LAI on *E. faecalis*. Some others only assessed the efficacy of LAI or PIPS and made no comparison with other methods (14). To the best of the authors' knowledge, no previous study has compared two

pulse widths of SWEEPS for elimination of *E. faecalis* biofilm. Thus, this study aimed to compare the efficacy of two pulse widths of SWEEPS for elimination of *E. faecalis* biofilm from the extracted root canals under in vitro conditions.

Materials and Methods

This in vitro, experimental study was conducted on single-rooted single-canal maxillary incisors and canine teeth, and mandibular incisors, canines, and premolar teeth that had been extracted due to poor periodontal prognosis or as part of orthodontic treatment. The study protocol was approved by the ethics committee of the university (IR.IAU.DENTAL.REC.1399.308).

Eligibility criteria
The inclusion criteria were extracted single-rooted single-canal teeth with sound, caries-free straight roots with no history of endodontic treatment, and no apical resorption. Teeth with calcifications, coronal caries, fracture, or curved roots were excluded.

Sample size
The sample size was calculated to be 8 in each of the 4 experimental groups, and 2 in each of the 3 control groups according to a study by Korkut et al, (5) assuming α=0.05, =0.2, mean standard deviation of the log colony count to be 0.73, and effect size of 0.65 using one-way ANOVA power analysis of PASS 11. The teeth were selected by convenience sampling.

Specimen preparation
The roots were cleaned from the periodontal ligament residues and calculus by a curette. The teeth were then decoronated such that 13 mm of the root length remained. Next, a #15 K-file (Dentsply Maillefer, Ballaigues, Switzerland) was used to ensure apical patency. The root canals were subsequently prepared to F3 by ProTaper rotary system (Dentsply Maillefer, Ballaigues, Switzerland). After using each file, the root canals were rinsed with 2 mL of 2.5% NaOCl by using a syringe and a 27-gauge needle. The smear layer was removed by using 5.25% NaOCl for 1 minute, followed by a rinse with saline and subsequent irrigation with 17% EDTA for 1 minute. A final rinse with saline was also performed for 1 minute. Glass ionomer was applied on the root surface to seal the apical end and accessory canals. The teeth were then placed in microtubes, and autoclave-sterilized at 121°C for 20 minutes (7).

Bacterial inoculation
Pure *E. faecalis* was obtained from the Pasteur Institute of Iran and cultured on blood agar for 24 hours. Microbial suspension was prepared by mixing the pure culture with 2 mL of saline. Next, the root canals were filled with 10 µL of the microbial suspension by an insulin syringe and incubated at 37 °C and 100% humidity for 28 days. Microbial inoculation of the canals was repeated every 2 days by using fresh microbial suspension during this time period. The roots (n=38) were then randomly assigned to 4 experimental groups (n=8), and 3 control groups (n=2).
In group 1, the SWEEPS technique was performed using Er:YAG laser (Light Walker, Fotona, Ljubljana, Slovenia) with 2940 nm wavelength, super-short pulse (SSP) mode with 50 µs pulse width, 0.3 W power, 15 Hz frequency, and 20 mJ pulse energy by using a laser tip with 600 µm diameter. The laser tip was positioned in the coronal part of the canal orifice. Saline was injected into the canal by a 27-gauge irrigation needle and laser was irradiated for 40 seconds. In group 2, Er:YAG laser was used with the same parameters reported for group 1. However, NaOCl was injected into the canal (instead of saline) by a 27-gauge irrigation needle.In group 3, Er:YAG laser was used with the same parameters reported for group 1, but in ultra-short pulse (USP) mode with 25 µs pulse width.
In group 4, Er:YAG laser was used with the same parameters reported for group 3 but NaOCl was injected into the canal as irrigant by a 27-gauge irrigation needle.
In group 5 (positive control), bacterial inoculation was performed but with no

subsequent disinfection protocol. In group 6 (negative control), bacterial inoculation was performed and the disinfection protocol was carried out by root canal irrigation with NaOCl injected into the canal with a 27-gauge needle. However, no laser irradiation was performed. In group 7, sterilization was performed with no bacterial inoculation.

Microbiological analysis
Each root was transversely divided into three sections of coronal third, middle third, and apical third. A low-speed endodontic hand-piece, a #4 Gates-Glidden drill, and #30 and #35 Hedstrom hand files were used to collect 0.01 g dentin chips from the root canal walls containing biofilm to assess the antimicrobial efficacy of the tested modalities. For colony counting, dentin chips were placed in sterile test tubes containing 2 mL of saline and mixed for 20 seconds. Next, they were diluted 10 times, and 10 µL of each suspension was cultured on brain heart infusion agar and incubated at 37 °C for 24 hours. The number of *E. faecalis* colonies was then counted and reported for each group.

Statistical analysis
Due to non-normal distribution of data as shown by the Kolmogorov-Smirnov test, comparisons were made by the Kruskal-Wallis and Dunnett tests. Level of statistical significance was set at 0.05.

Results

Table 1 presents the measures of central dispersion for the colony count in the study groups. The colony count was the highest in the positive control group, and the lowest in the USP-NaOCl and negative control (NaOCl) groups. The Kruskal-Wallis test showed a significant difference in colony count among the groups (P=0.005). Thus, pairwise comparisons were performed by the Dunnett test (Table 2). The results showed that all experimental groups had significantly lower colony count than the positive control group (P<0.05). The negative control group showed significantly lower colony count than all other groups (P<0.05) except for USP-NaOCl and USP-saline groups (P>0.05). The USP-NaOCl group showed significantly lower colony count than all other groups (P<0.05) except for negative control and USP-saline groups (P>0.05). The SSP-NaOCl group indicated significantly lower colony count than all other groups (P<0.05) except for USP-saline group (P>0.05). The USP-saline group had significantly lower colony count than all other groups (P<0.05) except for the negative control, SSP-NaOCl, and USP-NaOCl groups (P>0.05). Also, SSP-saline group had significantly lower colony count than the positive control group and significantly higher colony count than all other groups (P<0.05).

Discussion

This study compared the efficacy of two pulse widths of SWEEPS for elimination of *E. faecalis* biofilm from the extracted root canals under in vitro conditions. The results showed that the USP mode, especially in combination with NaOCl irrigation, had greater antimicrobial effects on *E. faecalis* than the SSP mode. Also, lack of a significant difference in colony count between the SSP-NaOCl and USP-saline groups indicated that in case of unavailability of NaOCl, the USP mode along with saline irrigation can have the same optimal efficacy for elimination of *E. faecalis* as SSP-NaOCl. However, its efficacy would be definitely lower than that of USP-NaOCl.
Cheng et al. (16) evaluated the antimicrobial efficacy of Er:YAG LAI by using NaOCl against *E. faecalis* and showed that it was capable of complete elimination of *E. faecalis* biofilm from the root canal walls and may be used as a successful protocol in endodontic treatments. Thapak et al. (17) compared the efficacy of Er:YAG laser, sonic irrigation, and CSI for smear layer removal, and reported that Er:YAG laser left the lowest amount of residual smear layer in the apical third of the root canals. Korkut et al. (5) compared the smear layer removal efficacy and antibacterial activity of Er:YAG (PIPS), Nd:YAG, and diode lasers and the CSI and showed that diode and

Table 1

Measures of central dispersion for the colony count in the study groups

Groups	Mean	Standard error	Minimum	Maximum
Control	3.03	0.06	2.95	3.15
SSP/NaOCl	0.40	0.01	0.38	0.44
SSP/Saline	1.25	0.11	1.05	1.45
USP/NaOCl	0	0.00	0.00	0.00
USP/Saline	0.27	0.04	0.22	0.37
NaOCl	0	0.00	0.00	0.00

Table 2

Pairwise comparisons of the groups regarding colony count by the Dunnett test

Groups	Control	SSP/ NaOCl	SSP/ Saline	USP/ NaOCl	USP/ Saline	NaOCl
Control	-	0.001	0.005	0.002	0.000	0.002
SSP/NaOCl		-	0.049	0.009	0.445	0.009
SSP/Saline			-	0.037	0.037	0.037
USP/NaOCl				-	0.119	1
USP/Saline					-	0.119
NaOCl						-

Er:YAG (PIPS) lasers were significantly more effective than the CSI with NaOCl and Nd:YAG laser for smear layer removal and reduction of *E. faecalis* count. Olivi and DiVito (12) evaluated the clinical techniques and protocols of PIPS and observed that photons are emitted with very low energy and microsecond pulse rates. Irradiation of irrigant with a laser pulse warms it up, forming a vapor bubble at the end of the laser tip, which further expands and bursts, forming a second bubble. Resultantly, a turbulent photo-acoustic stream moves the irrigant in the three-dimensional root canal space. They added that the speed of waves in the PIPS technique in areas close to the laser tip is 20 times the rate in ultrasonic irrigation; in farther areas from the laser tip, this rate is 10 times higher than the rate in ultrasonic irrigation. Kihara et al. (18) analyzed the irrigant stream in LAI and assessed the effect of position of laser tip in this regard. They found that placement of laser tip in the pulp chamber resulted in formation of a fast stream in the entire root canal system immediately after development of the vapor bubble. In contrast, placement of the tip in the apical part of the root canal led to formation of a fast stream due to development of secondary cavitation bubbles, which was limited to the apical region. As mentioned earlier, numerous studies have reported significantly improved antimicrobial activity against *E. faecalis* in Er:YAG LAI, and the SWEEPS technique has shown superior efficacy in elimination of *E. faecalis* compared with the conventional techniques (2, 5, 10, 12, 13,16, 19-21). Comparison of the efficacy of two different pulse widths of SWEEPS was the main strength of the present study, which has not been evaluated in any previous study. Thus, there was no similar study to compare our results with.

In vitro design, which limits the generalizability of the findings, evaluation of only single-rooted and single-canal teeth, and assessment of only one type of microorganism (*E. faecalis*) were among the

limitations of this study. Future studies are required on other tooth types with anatomical complexities, and other microorganisms Authors should discuss the results and how they can be interpreted from the perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

Conclusions

Within the limitations of this in vitro study, the results showed stronger antibacterial activity of the USP than the SSP mode against *E. faecalis* biofilm in extracted root canals. It appears that application of SWEEPS with the USP mode combined with NaOCl irrigation would be effective for elimination of *E. faecalis* biofilm from the root canal system. Moreover, in cases where NaOCl cannot be used (as in open apex teeth) and there is a risk of extrusion into the periapical tissue and hypochlorite accident, USP-saline can serve as an effective alternative for elimination of *E. faecalis.*

Clinical Relevance

This study aims to find the best parameters of SWEEPS technique for disinfection of root canals by eliminating E. faecalis.

Conflicts of Interest

The authors declare no conflict of interest.

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ORIGINAL ARTICLE

YouTube™ as a supplemental learning source for undergraduate dental students

ABSTRACT

Aim: *The objective of this study was to investigate, through a survey, the use of YouTube™ by dental students. Subsequently, the educational value of YouTube™ videos on 3 hot topics in endodontics was evaluated.*
Methodology: *The 3-, 4-, 5-, and 6-year dental students from the University of Parma were invited to complete an online questionnaire consisting of 20 multiple-choice questions regarding their use of YouTube™. Subsequently, YouTube™ videos were searched for the following topics: "root canal filling with single-cone technique and calcium silicate cements (CSCs)", "regenerative endodontics" and "guided endodontics". Data of interest were extracted from each video, and a specific scoring system was applied to evaluate scientific soundness, quality, and educational value.*
Results: *Although only a minority of students responded that they accessed the YouTube™ platform primarily for study purposes, 93.3% of dental students watched videos for educational pursuit, particularly for the disciplines of Restorative Dentistry, Prosthodontics, and Endodontics. Among the videos on Endodontics, the most viewed were those on access cavity opening.*
Analysis of 64 selected videos revealed that the majority were uploaded by private users and came from the United States. The average number of views was 6535, 3592,5 and 1143, respectively for videos on root canal filling with single-cone technique and CSCs, regenerative endodontics and guided endodontics. 46% of the videos on root canal filling with single-cone technique and CSCs had significant commercial bias. 71.8% of the videos were judged to be useful or highly useful for the students.
Conclusions: *YouTube™ videos currently represent an important auxiliary learning source for dental students, however there are currently no control mechanisms to verify the soundness of the information conveyed.*

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Introduction

The way students learn evolves over time, in response to the sources available and accessible to them (1) and adapting to the surrounding environment conditions, as the recent pandemic has shown (2). In addition to traditional learning tools, such as written notes and textbooks, students are increasingly using e-learning tools, including online educational videos (3). Video, combining visual and verbal elements, has the potential to be a more effective way to deliver instructional material than text or static images alone (4). According to a surveys conducted in the United States, videos uploaded to YouTube™ are the most widely used non-curricular resource by dental students (5) . Youtube™, launched in 2005 and owned by Google, is the currently largest Internet video-sharing website and it is the second most visited website in the world (6). Dental students benefit from several advantages when using YouTube™ for educational videos: 24/7 access, ability to view the content an unlimited number of times, the opportunity to interact with other users in the comments section, and exposure to similar videos recommended by the algorithm. By using YouTube™ as an educational source, students can practice self-directed learning, a skill they will need for lifelong continuing education (7). Despite these positive aspects, there are also drawbacks, in particular concerning the quality and reliability of videos. While YouTube™ has established guidelines for content related to spam, deceptive practices, sensitive content, violent and dangerous content, regulated goods, and copyright, there is no specific mechanism to guarantee the scientific accuracy and clinical relevance of medical education videos, including dentistry. This lack of control can lead to the dissemination of misleading or biased information, potentially impacting the learning of dental students, especially among students with underdeveloped critical thinking skills.
The quality of YouTube™ videos for student learning has been previously investigated for selected topics, including root canal preparation (8), access cavity preparation (9), pulpotomy and pulp cupping (10), with contrasting results.
The aim of this study was to investigate the use of YouTube™ by dental students from a Northern Italian dental school, with particular reference to endodontics, and to assess the quality of videos on three hot topics in endodontics.

Materials and methods

Survey
Between November 2023 and January 2024, 101 students attending the 3th, 4th, 5th, and 6th years of the Dental School at the University of Parma were invited to participate to a survey on their use of the YouTube™ platform through a Google Forms. The survey was approved by the local research ethics board (protocol number 22180/2024). Students were informed about the purpose of the survey, that their responses would be anonymous, and that their participation would not affect their academic evaluation.
The questionnaire consisted of the following 20 multiple-choice questions.

1. Have you ever used the YouTube™ platform?
2. How long have you been visiting the YouTube™ website?
3. How often do you visit the YouTube™ website?
4. Since you have been a university student, have you ever used YouTube™ for training or study purposes?
5. How many professors use videos uploaded to YouTube™ in their classes?
6. What is your primary use of YouTube™?
7. Do you find that videos on dental clinical procedures on YouTube are a useful tool for students?
8. How often do you refer to a video on YouTube to prepare for an exam?
9. In which of the dental subjects do you feel that YouTube™ videos can be most helpful?
10. Would you recommend YouTube™ videos to your classmates as a tool to supplement the teaching material?

11. Do the teachers of the Dentistry Course recommend or advise watching videos on YouTube™ to learn more about topics?
12. How do you rate the average level of evidence-based videos you have watched for study purposes?
13. Are the YouTube™ videos consistent with what is explained in class?
14. Would you like your teachers to upload educational videos to YouTube™?
15. Would you find it useful to watch videos on YouTube™ prior to perform a clinical procedure that you have never done before?
16. Have you already taken or are you taking the endodontics course at your university?
17. How often have you searched for videos on endodontics on YouTube™?
18. Would you recommend to your colleagues watching videos on YouTube™ for endodontic procedures for better learning and a better approach to the clinical side of the subject?
19. For what topics related to endodontics have you visited YouTube™?
20. What do you think is the level of evidence-based videos on endodontics that you have seen on YouTube™?

The results were obtained directly from Google Forms, maintaining anonymity, and analysed using Microsoft Excel 15.13.3 (Microsoft Corporation, Redmond, WA, USA) and Prism 4.01 (GraphPad software, San Diego, CA, USA). Answers were reported as percentages.

Assessment of endodontic YouTube™ videos

We selected the following three endodontic hot topics:

-root canal obturation with single cone technique and calcium silicate cements (CSCs);
-regenerative endodontics;
-guided endodontics.

These topics were chosen because a previous study showed that they were scarcely addressed in Italian dental schools (11). We hypothesized that students might be interested in further exploring these topics on their own searching on YouTube™.

The following queries were used: "bioceramic sealer", "single cone obturation", "single cone technique", "single cone bioceramic obturation", "one cone technique", "hydraulic condensation technique", "Endosequence BC sealer", "bioceramic obturation", "regenerative endodontics", "endodontic regeneration", "endodontic revascularization", "endodontic revitalization", "guided endodontics", "dynamic navigation in endodontics". Queries where constructed based on tags found in pertinent videos. The search was carried out using an incognito window with cache clearing and an unregistered browser to prevent the algorithm from selecting videos based on history. The default settings were maintained without any filter, and the videos were sorted by relevance. Considering that more than 90% of Internet users only consult the first 3 pages of search engines (12), the first 20 videos were considered for each query. After removing duplicates, the following exclusion criteria were applied to select the videos to be included:

1. videos not in English;
2. videos not dealing with the topic of interest;
3. videos on other endodontic procedures;
4. videos without written or verbal explanations;
5. videos shorter than 3 minutes.

An account was created to store the included videos. The following data were extracted for each video: video duration (minutes), number of views, days since upload, number of likes and dislikes, type of user who uploaded the video (private, company or academic institution), country. The view ratio (number of views / days since upload) was calculated (13).

To evaluate the educational value of each video, a specific 5-item scoring system, was used (Table 1). Each item will be assigned a value of 0 (item not adequately addressed in the video) and 1 (item adequately addressed in the video). A total score was assigned to each video adding the score assigned to each item. In addition, a modified version of the Global Quality Score (Table 2) was used to assess reliability and educational quality of the videos. This

evaluation tool, although non-validated, has been commonly used for the assessment of the content quality of online resources as it rates the quality and usefulness of online resources with a 1 to 5 scale (10, 14, 15).
The evaluation was performed independently by 2 raters previously calibrated for each item. In case of disagreement, a third rater was involved.
Categorical data are presented as number and percentages. Continuous data are presented as median and interquartile range (IQR) because at the Shapiro-Wilks test they shoved a non-normal distribution.
The collected data was compared between the three topics. Chi-2 test or Fischer exact test were used to compare categorical data in a 3x2 contingency table, followed by a 2x2 test with Bonferroni correction when significance was found.
Continuous data were compared with the non–parametric test of Kruskal-Wakllis followed by a Mann-Whitney U test with Bonferroni correction when significant. Data were analyzed using Stata v. 12.0 (College Station, TX).

Results

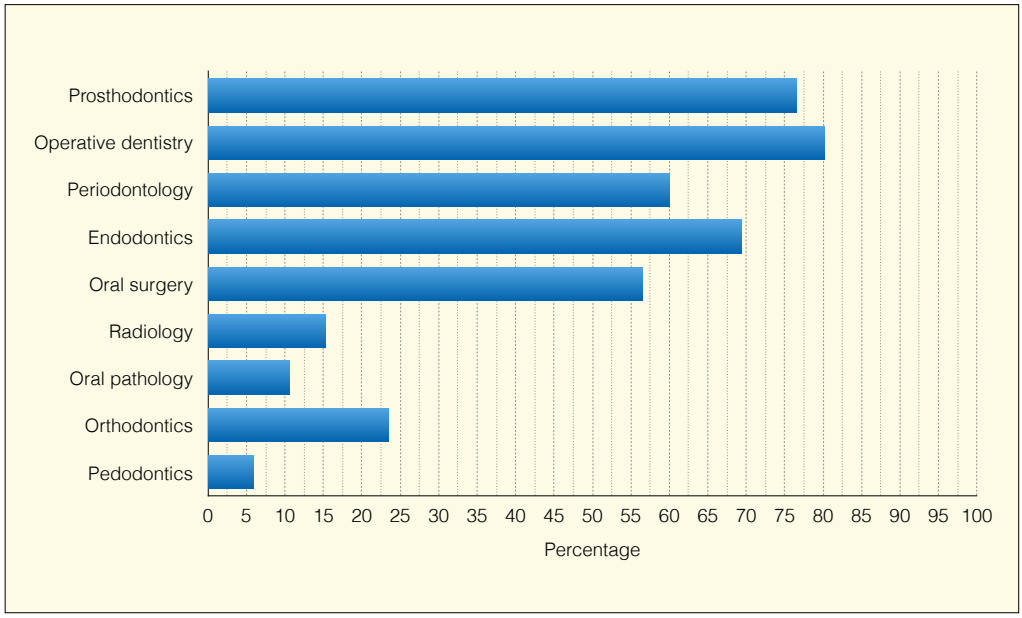
Out of 101 students, 89 (88.1%) responded to the questionnaire. All students had used YouTube™ at least once, and 82% had been using it for more than five years. Regarding usage frequency, 34.8% of students used YouTube™ weekly and 38.2% visited it daily. Although entertainment was the primary reason for using YouTube™ (74.2%), almost all students (93.3%) had used the platform for study purposes at least once. Additionally, 69.7% reported using YouTube™ often or very often to prepare for exams. Figure 1 illustrates responses to the question, "In which dental subjects do you feel that YouTube™ videos are most helpful?"
Further key results were:
- 80.9% of respondents believed that the level of evidence-based videos they watched for study purposes was average;
- 60.7% thought the content of YouTube™ videos was consistent with what was explained in class;
- 96.6% stated they would find it useful to

Table 1

Scoring system used to assess the educational value of the videos

Item	Score=0	Score=1
1 Global scientific soundness	The information conveyed is not aligned with current scientific knowledge	The information conveyed is aligned with current scientific knowledge
2 Commercial bias	The information conveyed has primarily commercial purposes	The information conveyed has not primarily commercial purposes (simply referencing market products does not automatically determine a commercial bias)
3 Quality of the clinical procedures	Clinical procedures are not shown OR the clinical procedures shown do not comply with current quality standards OR clinical procedures are not exhaustively described	The clinical procedures shown comply with current quality standards AND clinical procedures are exhaustively described
4 Audio and image quality	The image quality is poor OR text is not legible OR and the audio speech is not comprehensible	The image quality of the images is good AND text is legible AND and the audio speech is comprehensible
5 Comparison with other techniques	No reference is made to other techniques for the same purpose	The advantages and disadvantages of the technique are highlighted by comparing it to other techniques with the same purpose

Figure 1
Summary of the answers to the question "In which of the dental subjects do you feel that YouTubeTM videos can be most helpful?"



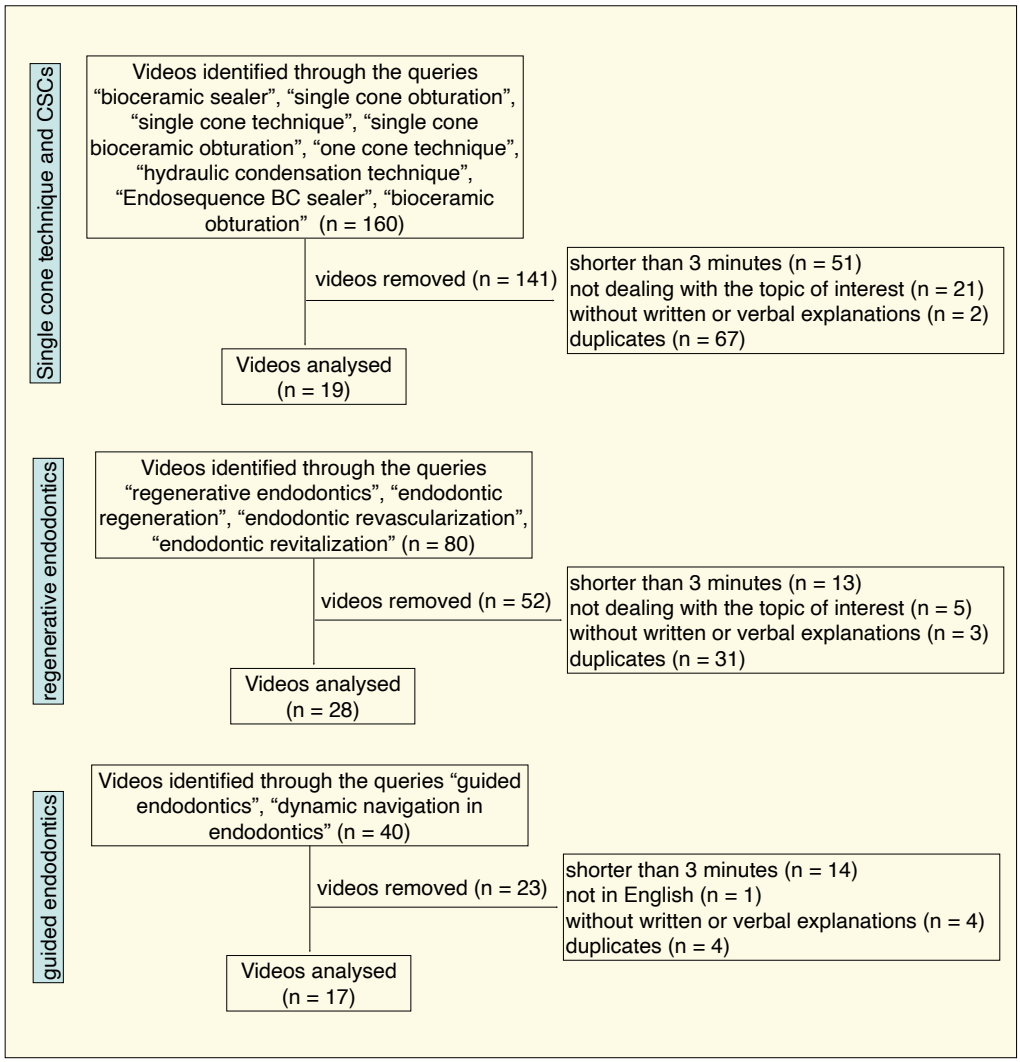


Figure 2
Flowchart of video selection.

Table 2

Modified version of the Global Quality Score

Score	Explanation
1	The video is of poor quality and content; the most important information does not appear. No or almost no utility for the students.
2	The video is of poor quality and content; some information appears, but some of the most relevant topics do not appear. Low utility for the students.
3	Moderate quality and fair fluency of content; some important information is adequately discussed, but others are less so. Average utility for the students.
4	Good quality and content; most of the relevant information is discussed, but some important topics are not. Useful for the students.
5	Excellent quality and content. Highly useful for the students.

watch videos before performing a clinical procedure for the first time.
The most-watched topics on YouTube™ included access cavity opening (75.8%), root canal shaping (64.5%) and root canal obturation (64.5%). Only 12.4% of students would not recommend using YouTube™ for endodontic procedures. Answers to questions regarding teacher usage were:
- 50.6% of students said a few teachers used YouTube™ videos in their lessons;
- 43.8% said some teachers used them;
- 61.8% reported that teachers sometimes recommended watching YouTube™ videos to learn more about topics;
- 31.5% said teachers never recommended them.
Despite this, 85.4% of students wanted teachers to upload educational content to YouTube™, 86.5% found the platform useful for learning, and 91% would recommend it to their classmates as a supplementary learning tool.

Video analysis

The video selection process is shown in Figure 2, and the main characteristics of the selected videos are summarized in Table 3. The longest video, titled "Pulp Revitalization-regeneration. Which one?", was uploaded on August 1st, 2021, by Dr. Hussain Al-Huwaizi from Iraq. It received 637 views. The top-viewed video, "Basic Hydraulic Condensation Technique", uploaded on September 27, 2013 by Dr. Allen Ali Nasseh (US), received 44,487 views and the most likes (n=765). A video titled "Can We Regenerate Our Teeth?" posted on the official channel of Meducator, a McMaster University's open-access, peer-reviewed undergraduate health sciences journal, had the highest view ratio of 97.7. Most of the videos (45 out of 64, 70.3%) were uploaded by private users and only two videos, both on "regenerative endodontics", were uploaded by academic institutions. There were significant differences in the number of views, likes, and view ratios across topics.
Key results of post hoc analysis revealed that:
-videos on "guided endodontics" had significantly fewer views and likes compared to other topics;
-videos on "single cone technique and CSCs" had a higher view ratio than those on "guided endodontics".
- a significantly higher percentage of videos on the "single cone technique and CSCs" topic were uploaded by companies (47.4%) compared to "regenerative endodontics" (14.3%).
Videos were uploaded from 12 countries, with the largest contributors being United States (26.6%), United Kingdom (18.7%), and India (18.7%). The country of origin could not be determined for two videos.
The average total score, based on a 5-item scoring system, was the same across all three topics (3.8/5). However, there were significant differences between topics for two specific items. Videos on "single cone technique and CSCs" were more likely to have primarily commercial purposes compared to "regenerative endodontics" videos and videos on "regenerative endodontics" were more likely to show clinical procedures that did not comply with current quality standards compared to "single cone technique and CSCs" videos. No videos scored 1 or 2 on the modified Global Quality Score (Table 5). Most were rated as useful for students, and there were no significant differences in usefulness among the topics.

Table 3

Characteristics of the selected videos

	single cone technique and CSC (n=19)	regenerative endodontics (n=28)	guided endodontics (n=17)	P
video lenght (s)	532 (287-830)	626,5 (276,5-1336)	657 s (470-2301)	0,511
Days since upload	1.096 (800-1747)	1.198 (794,5-1714)	827 (335-1228)	0,184
Number of views	6.535 (3138-16807)	3592,5 (1901-8961,5)	1.143 (424-1917)*†	0,001
Number of likes	175 (54-255)	127,5 (38,5-239)	16 (11-48)*†	<0,001
view rate	6,5 (3,0-9,8)	3,2 (1,2-5,6)	2.3 (0,9-4,5)*	0,046

*All data are reported as median (IQR) - *= Significant vs single cone technique - †= Significant vs regenerative endodontics*

Table 4

Results of the 5-items educational value scoring system

	Single cone technique and CSC (n=19)	Regenerative endodontics (n=28)	Guided endodontics (n=17)	P
1 Global scientific soundness	100%	100%	100%	1
2 Commercial bias	68%	100%*	88%	0,006
3 Quality of the clinical procedures	84%	46%*	76%	0,034
4 Audio and graphical quality	89%	89%	76%	0,968
5 Comparison with other techniques	47%	50%	41%	0,903

*The numbers refer to the percentages of score 1 assignments. *=significant vs single cone technique.*

Discussion

Endodontics, as a specialty, is one of the dental disciplines that causes the most stress among students (16). This is due to its inherent complexities and the technical precision required for successful outcomes. Additionally, it is the only dental discipline where many procedural interventions are performed "in the dark," because once the operator enters the root canal system, he cannot "see" and "do" simultaneously (17). Furthermore, what little the operator can see within the pulp chamber is even less visible to a student observing the treatment, unless an operating microscope connected to a monitor is used. For these reasons, videos of endodontic pro-

Table 5

Results of modified Global Quality Score

Score	Single cone technique and CSC (n=19)	Regenerative endodontics (n=31)	Guided endodontics (n=17)	P
1	0%	0%	0%	NA
2	0%	0%	0%	NA
3	21%	32%	29%	0,503
4	53%	57%	41%	
5	26%	11%	29%	

The numbers refer to the percentages of score assignments. NA=not available.

cedures could be highly effective for learning. The widespread accessibility of video platforms has made it easy and immediate to access a vast array of learning resources. However, this has also quickly raised the issue of misinformation, because of the dissemination of online videos where the content is not subjected to rigorous review (18). In this context, the present study aimed, for the first time, to explore how dental students from an Italian dental school utilize YouTube™, specifically in the field of endodontics, and to evaluate the quality of videos related to three emergent topics in endodontics.

Our survey corroborated results from other studies investigating the use of YouTube™ by dental students (19-21). While YouTube™ was primarily used for entertainment, nearly all respondents reported using it for educational purposes, finding it particularly useful for operative dentistry, prosthodontics, and endodontics. A similar trend was observed among students from five American universities (New York University, University of Texas Health Science Center, Tufts Health Sciences, Roseman University of Health Sciences, and Western University of Health Sciences), where a comparable survey was conducted (20). These disciplines are often introduced early in the undergraduate curriculum, when students have limited clinical experience. To compensate, students frequently turned to online videos for supplementary learning. Interestingly, although students recognized that online videos might not meet high-quality standards or fully align with their formal education, they still considered them useful for gaining indirect experience before performing clinical procedures. However, it is important to note that while students widely used YouTube™, its integration into formal teaching remained limited. Only a minority of teachers supplemented their lessons with YouTube™ videos or recommend specific content to students. One suggestion from students, which the authors endorse, is that teachers should create and upload educational videos to YouTube™ to complement their lessons. While this would require efforts, including obtaining necessary permissions to avoid privacy violations, the potential benefits are significant (22). First, this would ensure that the content is high-quality and consistent with the curriculum and clinical environment of the school. Additionally, any uncertainties about the video content could be directly addressed with the teacher, fostering interactive learning. Furthermore, the video repository could expand over time, providing up-to-date resources for future students. While several dental schools have already established official YouTube™ channels, many institutions have yet to capitalize on this valuable opportunity. To bridge this gap, it would be advantageous for institutional bodies

to actively promote and financially support the development of high-quality YouTube™ channels.

In the second part of our study, we evaluated the educational value of YouTube™ videos. We considered three current hot topics in endodontics: "single cone technique and CSCs," "regenerative endodontics," and "guided endodontics". These three topics were selected due to their innovative nature, high clinical relevance, and their potential to shape future clinical practices (23). However, like many innovations, they have not yet been fully integrated into undergraduate curricula (11) which may lead students to seek additional information through online platforms. The single cone obturation technique, though long established, has gained renewed attention with the introduction of bioceramic cements. These materials offer several advantages over traditional cements, such as improved biocompatibility, superior sealing ability, and strong antibacterial effects (24). Regenerative endodontics presents an alternative to conventional apexification techniques for treating pulp necrosis in immature teeth. This biologically-based treatment promotes not only the resolution of symptoms but also continued root development, reducing the risk of root fracture (25). Guided endodontics, which adapts technologies from implant surgery, is particularly useful for locating severely calcified canals and performing precise endodontic surgery. This technique relies on physical templates or dynamic navigation systems based on three-dimensional imaging (26).

Videos on the single cone technique and CSCs garnered more views, likes, and higher view rates compared to the other two topics. This popularity may be attributed to the technique's simplicity, speed, and the growing interest in bioceramic cements. Moreover, root canal filling is a routine procedure, attracting a wide audience. In contrast, the other two topics, while clinically significant, are applicable to a narrower range of cases, which may explain the lower engagement. Notably, videos on the single cone technique and CSCs showed differences from the other two categories in terms of two variables: the percentage of videos uploaded by commercial entities and the percentage of videos that received a score of 0 for item 2 in our scoring system. A score of 0 was given when the primary intent of the video appeared to be commercial rather than educational. The bioceramic cement market has seen a surge in commercial interest, leading manufacturers to promote their products aggressively through various channels, including YouTube™.

As YouTube™ is widely used by both dental students and practitioners (20, 27), it is unsurprising that companies leverage this platform for promotional purposes. While commercial bias did not necessarily affect the overall scientific accuracy of the videos (item 1), it is important for viewers to be aware of this bias and exercise critical judgment when interpreting the content. For videos on "regenerative endodontics," over half received a score of 0 for item 3, which evaluates the quality of clinical procedures. Upon further investigation, we found that most of these videos originated from the US and UK, contrary to our initial assumption that lower-quality videos might come from regions with less developed dental standards. According to item 5 of our scoring system, watching a single video is typically insufficient for gaining a comprehensive understanding of a particular technique. Viewers are encouraged to watch multiple videos on alternative approaches to develop a more balanced perspective on the pros and cons of different methods. The modified Global Quality Score did not reveal any significant differences in quality among the three topics. Overall, the videos were of good quality, though some key aspects were omitted, even when most of the essential information was covered.

Our findings contrasted with those of other studies that assessed the quality of YouTubeTM videos on different endodontic topics. Falakaloğlu et al., evaluating 108 videos on root canal preparation, assigned a "poor quality" score to 63% of the videos (8). Kodonas et al.'s assessment of videos on pulpotomy and pulp capping was even more negative. According to their

analysis, most videos (85%) were classified as "poor" or "generally poor" in educational quality (10). Kaval et al. analyzed 60 videos on regenerative endodontic treatment procedures and assigned a lower average GQS score compared to our study (2.8±1.3 vs. 3.8±0.7) (28).
These discrepancies can be attributed not only to the different video selections but also to the inherent subjectivity of the scoring system used. Results more similar to ours were reported by Jamleh et al., who assessed the educational value of YouTubeTM videos on endodontic access cavity preparation. They found that most videos (70.7%) received a rating of "moderate to good" usefulness (9). On the other hand, our results are strongly consistent with the opinions of the interviewed students, who reported that YouTubeTM videos generally provided a valuable educational resource.
Most authors agree that, albeit the use of non-curricular resources like YouTube™ is beneficial for reinforcing learned concepts, exploring specialized topics, and fostering self-directed learning (29), these sources lack rigorous oversight. Consequently, they can disseminate inaccurate or incomplete information, which poses risks to the professional development of future dentists (8-10, 30). Addressing this issue is challenging. Effective educators must equip students with critical thinking skills, enabling them to discern valuable content from misinformation. Given the increasing reliance on non-curricular sources, it is imperative that educators prioritize the development of these skills in their students.

Conclusions

YouTube™ videos currently represent an important auxiliary learning source for dental students. However, due to the lack of content oversight, there is a risk of misleading or biased information being disseminated. To mitigate this potential threat to dental student learning, educators should curate a selection of reliable videos to share with students or recommend specific channels/broadcasters known for their accuracy and quality.

Clinical Relevance

Given the widespread student use of freely available video content for learning and the risk of exposure to misleading information, teachers should instruct students in the critical appraisal of contemporary media resources.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be considered as a potential conflict of interest.

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ORIGINAL ARTICLE

Comparative analysis of debris extrusion and instrumentation time among various endodontic file systems: an in vitro study

ABSTRACT

Aim: *Debris extrusion during endodontic procedures, characterized by the unintended displacement of root canal debris, poses significant clinical challenges, potentially leading to postoperative pain and infection. In this study, we aimed to evaluate the differences in debris extrusion and instrumentation time among various endodontic file systems.*
Methodology*: 120 mandibular first molars were included in the study, with 15 specimens in each group: Protaper Next, HyFlex CM, HyFlex EDM, WaveOne Gold, Reciproc Blue, Trunatomy, PTUltimate, and Rmotion. Both debris extrusion and instrumentation time for these systems were assessed. Descriptive analyses were performed, and statistical comparisons were made using the Kruskal-Wallis test (p<0.05).*
Results*: Protaper Next and HyFlex CM exhibited significantly higher mean debris extrusion compared to other systems. On the other hand, the remaining systems, showed lower mean debris extrusion. HyFlex CM was the most time-consuming, while WaveOne Gold, R-Motion, and Reciproc Blue were among the quickest. HyFlex EDM demonstrated a balanced performance, being efficient in both debris extrusion and time.*
Conclusions*: The findings suggest that while some systems significantly minimize debris extrusion and reduce instrumentation time, the choice of an endodontic file system should be guided by specific clinical conditions and operator preference based on our comparative analysis.*

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Introduction

Debris extrusion during endodontic procedures, defined as the unintentional displacement of root canal debris including bacteria and necrotic tissue beyond the apical foramen, is a critical concern due to its potential to cause inflammation and subsequent infection of periapical tissues (1). Studying debris extrusion from different endodontic files helps identify file designs and usage protocols associated with minimal extrusion. This not only mitigates the risk of periapical tissue damage but also contributes to improving the overall success rate of endodontic procedures (2).

The inherent variability in root canal anatomy, coupled with the diverse designs and materials of endodontic files, contributes to the complexity of debris extrusion. Nevertheless, gaining a understanding of how these factors influence debris extrusion is pivotal in identifying the most effective file designs and usage protocols. Such insights can significantly enhance the success rates of endodontic procedures (3, 4).

Despite numerous studies on debris extrusion in endodontics, most of them have focused on specific systems, given the multitude available in the market (5-7). However, as mentioned earlier, debris extrusion is a multifactorial phenomenon, and research methodologies vary considerably across the literature. Therefore, the primary aim of this research is to incorporate a diverse range of endodontic systems, encompassing both rotary and reciprocating systems, to enable impartial comparisons. This approach seeks to mitigate the methodological discrepancies that often impede the synthesis of systematic reviews in this field (8). The study will investigate the extent of debris extrusion and the time required for instrumentation with various endodontic file systems, including ProtaperNext, HyFlex CM, HyFlex EDM, WaveOne Gold, Reciproc Blue, Trunatomy, PTUltimate, and Rmotion. The null hypothesis posits that there is no statistically significant difference in debris extrusion and instrumentation time among the evaluated endodontic systems.

Material and Methods

The manuscript of this laboratory study has been written according to Preferred Reporting Items for Laboratory studies in Endodontology (PRILE) 2021 guidelines (9). After obtaining approval from the local Research Ethics Committee (opinion no. 5.731.282), the study included 120 mandibular first molars extracted for various reasons. Inclusion criteria were as follows: teeth with fully developed roots displaying separate foramina, curvature angles ranging between 15 to 20 degrees (10), absence of calcifications, resorption, or prior endodontic treatment, and an initial apical canal diameter equivalent to that of a #15 K-file (Maillefer Corp, Ballaigues, Switzerland). Subsequently, these teeth were meticulously disinfected through immersion in a 0.5% chloramine-T trihydrate solution for a duration of one week.

To ensure consistent initial conditions across all samples, the diameter of the mesiobuccal canal was standardized using a #15 K-file (Dentsply Maillefer, Ballaigues, Switzerland). Each file was gently inserted into the canal until it snugly fit within, and its tip was visible at the apical foramen. This process was conducted under the magnification of a dental operating microscope at 12.5x (Stemi 508; Carl Zeiss, Jena, Germany), which ensured precise visualization and placement. The working length (WL) for each canal was then established as 1 mm short of this measurement to maintain uniformity in measurement criteria across all specimens.

To further standardize the sample selection, only canals that met these specified criteria were included in the study. Any canal that did not fit these requirements was excluded and replaced with another specimen that matched the standardized conditions. Additionally, the study included a radiographic verification step to confirm the uniformity of canal configuration prior to the instrumentation procedures. All teeth were radiographed in both the buccolingual and mesiodistal dimen-

sions using a CDR Elite digital radiographic sensor (Schick Technologies), ensuring that all specimens adhered to a consistent anatomical baseline. This step was critical for addressing potential variability in root canal anatomy and minimizing its impact on the study outcomes. In this study, the standardization of the canal was specifically focused on the mesiobuccal aspect due to the exclusive instrumentation of this canal.

The sample size calculation was conducted using G*Power 3.1.9.4 software, developed by Heinrich-Heine-Universität Düsseldorf, Germany. The primary outcome of interest was the quantity of debris extruded. In accordance with a previous study by Mustafa et al. (11) the study aimed to detect a difference of 0.0018 between groups. With a standard error of 0.00165, a power of 0.80, and a significance level of 0.05, the calculated sample size necessary for the study would be 15 specimens per group.

Conventional access cavities were prepared by sectioning the crowns at the cementoenamel junction using a round diamond bur (Horico Dental Hpf; Ringleb, Berlin, Germany) attached to a low-speed handpiece driven by a micromotor, all while maintaining water cooling. This process yielded specimens measuring 13 mm in length, a measurement confirmed using a digital caliper (500 series, DIN 862; Mitutoyo, São Paulo, SP, Brazil).

Randomization

The specimens were subjected to random allocation using the Random Allocation Software, version 1.0.0, into eight distinct experimental groups, each consisting of 15 specimens. These allocations were made based on the specific instrumentation systems employed, which included ProtaperNext, HyFlex CM, HyFlex EDM, WaveOne Gold, Reciproc Blue, Trunatomy, PTUltimate, and Rmotion.

Instrumentation

Within the Protaper Next group, an X1 (17.04) PTN file (Dentsply Maillefer, Ballaigues, Switzerland) was employed in rotary motion, operating at a speed of 300 rpm with a torque of 2 N·cm. This instrument underwent three in-and-out movements (pecks), each having a stroke amplitude of 3 mm, in every third of the canal (cervical, middle, and apical) until it reached the WL, which was set at 1 mm short of the apical foramen. The same sequence was replicated using an X2 (25.06) instrument.

For the HyFlex EDM group, the OneFile instrument (25/~, variable taper) from the Hyflex EDM rotary system (Coltène, Altstätten, Switzerland) was utilized in rotary motion, functioning at a speed of 500 rpm with a torque of 2.5 N·cm. This instrument underwent the same type of motion with a similar amplitude and WL as that used for the X1 instrument in the PTN group.

For the HyFlex CM group, the instrumentation sequence was unique due to the absence of a 25.06 taper instrument. The protocol was as follows: A 25.08 instrument was initially used for cervical preparation, given its 19 mm length. This was alternated with a manual #10 file, with odontometry performed intermittently. Subsequently, instruments with specifications 20.04, 25.04, and 20.06 were used in sequence. Although this may seem unconventional, it was done this way to avoid using a 30.04 instrument, which would deviate significantly from the apical standard set by the other instruments.

In the WaveOne Gold group, the Primary file (25.07) from the WaveOne Gold system (Dentsply Maillefer, Ballaigues, Switzerland) was employed in reciprocating motion. This involved three in-and-out movements (pecks) with a stroke amplitude of 3 mm in the cervical, middle, and apical thirds of the canal, and this motion continued until the WL was reached.

In the Reciproc Blue group, the R25 instrument (25.08) from the Reciproc Blue system (VDW GmbH, Munich, Germany) was utilized in the same fashion as described for the WaveOne Gold group. The procedure involved the use of the Reciproc program on the motor.

For the Trunatomy group, the Trunatomy files were used in rotary motion, operating at a speed of 500 rpm with a torque of 1.5 Ncm. The instrumentation sequence began

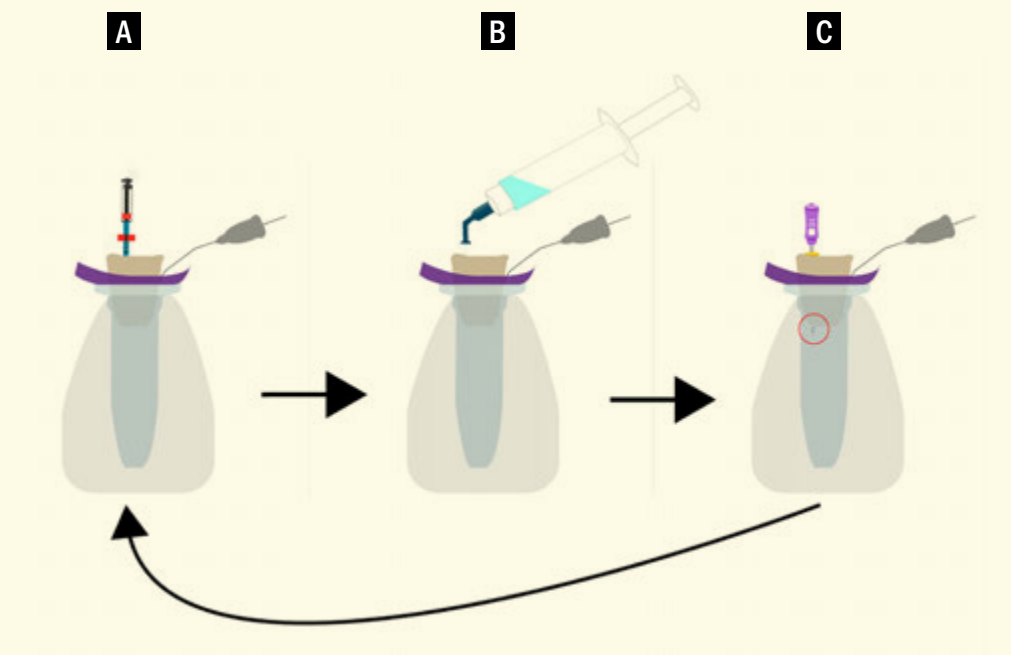

Figure 1
Illustration of the instrumentation protocol. **A)** An example of instrumentation using Reciproc Blue file; **B)** the irrigation protocol following every 3 in-and-out movements or one-third of root instrumentation; **C)** utilization of #10 K-type file extended 1mm beyond the apex for patency verification, with the red circle indicating the 1 mm extension beyond the apex.

with an orifice modifier (20.08) until reaching half the WL, followed by the use of a glider (17.02), small (20.04), and prime (26.04) instruments, all the way to the WL. For the ProTaper Ultimate group, the instrumentation sequence began with a Slider 16.04, followed by a Shaper 20.04. Subsequent instruments used were F1 20.07 and F2 25.08. It is important to note that the diameter of these files is 1.0 mm, unlike the 1.2 mm diameter commonly found in other instruments.

For the RMotion group, a #25 file with a .06 taper was used. The instrument was employed in the same manner as the WaveOne file, utilizing the WaveOne program on the motor for the procedure. The instruments were operated using an X-Smart Plus motor (Dentsply Maillefer, Ballaigues, Switzerland), with adjustments made for each specific system. It's important to note that, regardless of the system used, each instrument was dedicated to preparing a single root canal and was subsequently discarded. The mesiolingual canals remained untouched and did not undergo any instrumentation or irrigation during the entire experimental process. All canals were instrumented by a single operator to ensure consistency throughout the experimental procedures. The operator was an experienced endodontist with extensive clinical expertise and several published articles in the field. Given the operator's familiarity with both rotary and reciprocating techniques, no additional specific training was conducted prior to the experiment. This proficiency minimized variability due to operator influence.

During the instrumentation process, the specimens received irrigation with 3 mL of double-distilled water, administered using a side-vented needle (29G NaviTip; Ultradent Products Inc, South Jordan, UT) at intervals of every three in-and-out movements or after one-third of the root was instrumented. Following each movement and irrigation cycle, foramen patency was confirmed by using a #10 K-file that extended 1 mm beyond the foramen in all experimental groups (Figure 1).

Upon the completion of the instrumentation, a final irrigation was carried out using 1 mL of double-distilled water, without exceeding a total of 10 mL of irrigant, which was standardized for all specimens. Subsequently, the canals were aspirated using a capillary tip (Ultradent, South Jordan, UT) and then dried using paper points provided by the respective manufacturer of each system.

Manufacture of the apparatus for collecting and weighing extruded debris:
The amount of apically extruded debris after instrumentation was quantified according to the method proposed by Myers & Montgomery (12), and modified by other authors (5, 13). In all experimental groups, the Eppendorf tubes were placed in an incubator (Model EL–14; Odontobras, São Paulo, Brazil) and maintained at a consistent temperature of 70 °C for a continuous duration of 5 days. This period allowed for the complete evaporation of the double-distilled water from inside the Eppendorf tubes. Subsequently, each Eppendorf tube underwent three separate weightings on the same precision balance that was initially used. The average weight from these three measurements was recorded as the final weight of the Eppendorf tube, now containing the extruded debris. The calculation of the dry weight of the extruded debris (in grams) was achieved by subtracting the initial weight (that of the empty tube) from the final weight.

Evaluation of actual instrumentation time:
The instrumentation procedure for each specimen was meticulously timed using a digital stopwatch (Seiko, Japan). The timer was initiated when the instrument was put into motion inside the root canal and ceased when the instrument was withdrawn, providing the precise instrumentation time for each case.

Statistical analysis
The results obtained for debris weight and instrumentation time underwent statistical analysis using the software Jamovi v1.6.21 (https://www.jamovi.org). It's important to note that the Shapiro-Wilk test indicated a rejection of the assumption of data normality for both the quantity of extruded debris and the actual instrumentation time. Descriptive analyses were conducted, and the subsequent statistical analysis was carried out utilizing the Kruskal-Wallis test.

Results

Regarding debris extrusion, ProtaperNext and HyFlex CM are significantly different from the other file systems ($p<0.05$), showing the highest mean values. In contrast, HyFlex EDM, WaveOne Gold, Reciproc Blue, Trunatomy, PTUltimate, and Rmotion have significantly lower mean values of debris extrusion (figure 2 and table 1). In terms of instrumentation time, the data reveal that ProtaperNext, HyFlex CM, Trunatomy, and PTUltimate required longer times ($p<0.05$). Conversely, HyFlex EDM, WaveOne Gold, Reciproc Blue, and Rmotion showed significantly shorter instrumentation times ($p<0.05$). All numerical data and statistical differences between the groups are described in Table 1.

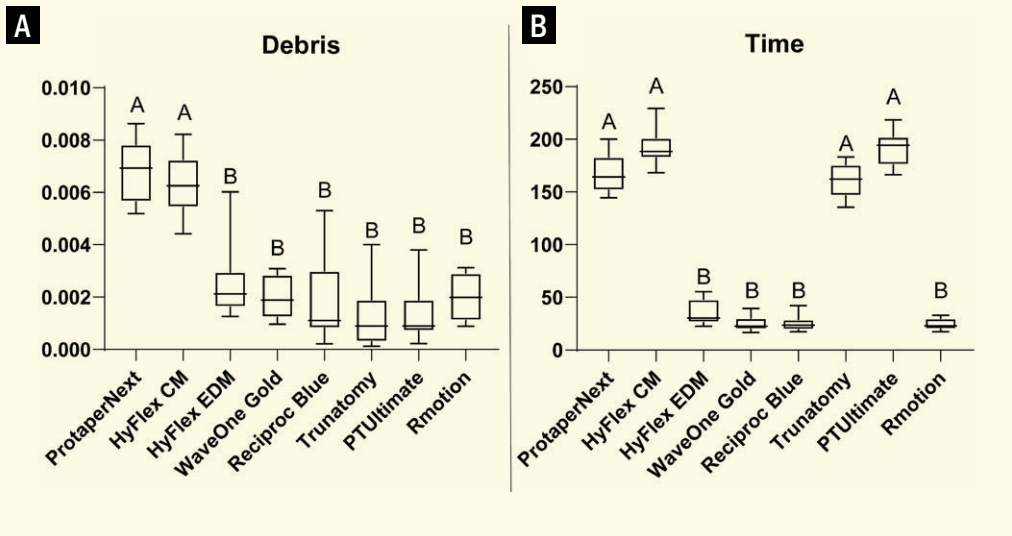

Figure 2
A) A box plot displaying the results related to debris extrusion across different endodontic systems, with varying letters indicating statistically significant differences among the groups; **B)** a box plot depicting the results concerning the time of instrumentation across different endodontic systems, with distinct letters indicating statistically significant differences among the groups.

Table 1

Differences between instrumentation systems regarding apical debris extrusion and time required for root canal instrumentation

Group	Debris		Time	
	Median±IQD	Mean±SD	Median±IQD	Mean±SD
ProtaperNext	0.0069±0.0019^{A}	0.0068±0.0012	164.330±28.870^{A}	168.905±17.392
HyFlex CM	0.0063±0.0016^{A}	0.0064±0.0012	188.350±17.025^{A}	191.660±17.372
HyFlex EDM	0.0021±0.0012^{B}	0.0025±0.0012	30.280±20.255 ^{B}	35.327±11.307
WaveOne Gold	0.0019±0.0014^{B}	0.0020±0.0008	22.560±8.015^{B}	24.923±7.014
Reciproc Blue	0.0011±0.0020^{B}	0.0019±0.0015	23.570±9.470^{B}	25.157±7.000
Trunatomy	0.0009±0.0012^{B}	0.0012±0.0011	162.230±26.740^{A}	161.615±5.675
PTUltimate	0.0009±0.0011^{B}	0.0013±0.0010	194.230±25.095^{A}	190.937±16.391
Rmotion	0.0020±0.0017^{B}	0.0020±0.0009	23.010±9.515^{B}	24.937±5.413
P-value*	<0,0001		<0,0001	

*Same superscript letters indicate no statistical difference between the groups, whereas different superscript letters indicate statistical difference. *Kruskal-Wallis test.*

Discussion

In summary, our study provides a evaluation of various endodontic instrumentation systems, with a specific focus on debris extrusion and instrumentation time. Consistent with existing literature (14-19), it is important to emphasize that all endodontic systems assessed in our study exhibited some degree of debris extrusion. Statistical analysis revealed that Protaper Next and HyFlex CM had the highest mean debris extrusion, and they were statistically similar in this respect. Conversely, the remaining systems, including Protaper Ultimate, HyFlex EDM, WaveOne Gold, Reciproc Blue, Trunatomy, and R-Motion, demonstrated lower mean debris extrusion, with no significant differences among them. Regarding instrumentation time, HyFlex CM proved to be the most time-consuming, while WaveOne Gold, R-Motion, and Reciproc Blue were among the quickest. These findings underscore the importance of considering multiple factors when choosing an endodontic system. The selection should not hinge solely on debris extrusion or time but should be an informed decision based on data. Our study's results led us to reject the null hypothesis. In our study, the curvature angles of all the teeth used were standardized to be between 15-20º (10). This standardization is a crucial consideration, as existing literature has established that canal curvature can influence both debris extrusion and instrumentation time (5,20-23). By maintaining a consistent curvature within this range (24), we aimed to minimize the influence of this variable, enabling a more focused evaluation of the instrumentation systems themselves. When interpreting the results, it is essential to bear in mind that variations in canal curvature in a clinical setting could potentially alter both the quantity of debris extruded and the time required for canal preparation.
To ensure consistency in instrumentation, we employed the same motor and strictly adhered to the manufacturer's guidelines for each system. Additionally, we used the last instrument with a similar taper and tip across all systems to standardize the process as closely as possible. It is important to recognize, however, that achieving complete standardization is nearly impos-

sible due to the diverse metallurgies, designs, tip, and taper variations in instruments used across different systems (25). This could be considered a limitation of our study, as these variations could potentially influence both debris extrusion and instrumentation time.

Specimens were irrigated with 3 mL of double-distilled water, utilizing a side-vented needle after every three in-and-out movements or when one-third of the root was instrumented (5). It is crucial to highlight this irrigation protocol, as inadequate irrigation can significantly influence debris extrusion (26). Moreover, the deliberate choice of double-distilled water as the irrigant was made to minimize methodological biases. In contrast to other commonly used irrigants such as sodium hypochlorite or chlorhexidine, double-distilled water evaporates without leaving any residues (26), thereby eliminating potential variables that could affect the study outcomes.

It is important to note that different irrigant activation techniques, such as passive ultrasonic irrigation, sonic irrigation, and manual dynamic agitation, have been shown to influence debris extrusion. A recent study by Ada et al. (2023) (27) demonstrated that passive ultrasonic irrigation caused significantly less debris extrusion compared to sonic irrigation and manual dynamic agitation, which aligns with our efforts to reduce extraneous variables in our study. These techniques, especially passive ultrasonic irrigation, have also been shown to improve bacterial elimination, which could further mitigate the risk of postoperative complications caused by apical debris extrusion. Future studies should consider comparing different irrigants and activation methods to more comprehensively evaluate their effects on extrusion and clinical outcomes.

The unintentional extrusion of debris and bacteria from root canals during root canal therapy has been the focus of extensive research in recent years (2, 6, 8, 28). Nevertheless, a consensus regarding the most reliable methodologies for measuring and quantifying extrusion remains elusive. Many studies explore factors contributing to extrusion, such as the type of instrumentation, root canal size and shape, and operator skill level (5, 29, 30). Our study rigorously adhered to established methodologies, drawing from existing literature (31), and even engaged a single operator to minimize variability. Despite these inherent challenges, in vitro studies of this nature provide invaluable insights. While it is impractical to conduct such experiments in a clinical setting, the findings furnish a scientific foundation that informs clinical practices and contributes to enhanced patient outcomes.

The kinematic factor's influence on debris extrusion is inconclusive in our study, as both rotary and reciprocating systems yielded similar results. This inconclusive influence aligns with some existing studies (3, 32), while contrasting with others that suggest a more definitive impact (33). This observation can potentially be justified by the balanced performance of low-taper files with reduced metallic mass, such as Trunatomy and Protaper Ultimate, when compared to reciprocating systems. The likely explanation for this balanced outcome could be the more conservative preparation approach employed by these files, which results in reduced debris production and, consequently, less extrusion. This suggests that the design features of the endodontic files, such as taper and metallic mass, may play a more significant role in debris extrusion than the kinematics of the system, a conclusion that aligns with existing research (2, 21, 34).

Recent studies have continued to explore the relationship between endodontic systems and apical debris extrusion. A systematic review (35) provides an updated perspective on this topic, investigating the risk of debris extrusion associated with both rotating and reciprocating instruments. This review emphasized the need for further exploration into the connection between extrusion and post-operative flare-ups, suggesting that while debris extrusion occurs in both systems, the flare-up risk might not solely be attributed to the instrumentation method but also to the instrument design and clinical. The review supports our findings that instru-

ment design, such as lower taper and reduced metallic mass, may play a more significant role in mitigating debris extrusion than kinematics alone.

Furthermore, recent advancements in endodontic motors, which offer enhanced control through functions such as apical reverse, apical stop, and adaptive torque control, could also influence debris extrusion. A study by Kılıç et al. (2023) (36) explored the effects of these functions, finding that while different kinematic modes, such as apical reverse and apical slow down, did not show statistically significant differences in debris extrusion compared to continuous rotation, these advanced features provide greater apical control, which could reduce the risk of excessive debris extrusion and postoperative complications. Although our study did not utilize motors with these advanced features, future research should consider their potential to further refine debris management during instrumentation.

It's important to note that when a sequence of instruments is employed, those with lower taper and reduced metallic mass tend to yield less extrusion (34). This is in contrast to other rotary systems like Protaper Next and HyFlex CM, which may feature more aggressive cutting blades, higher tapers, and greater metallic mass, consequently contributing to increased debris extrusion.

The clinical relevance of our findings is highlighted by the impact of debris extrusion on postoperative outcomes, particularly the risk of pain and flare-ups (35). Studies indicate that debris extrusion is strongly associated with postoperative pain (37) due to the extrusion of infected material into periapical tissues, leading to irritation and inflammation. Our data show that Protaper Next and HyFlex CM extruded significantly more debris compared to other systems, aligning with findings that rotary systems, particularly those with more aggressive cutting edges and greater taper, can increase the risk of postoperative discomfort. Conversely, the other systems in our study - Protaper Ultimate, HyFlex EDM, Trunatomy, Reciproc Blue, WaveOne Gold, and R-Motion - demonstrated lower debris extrusion. This reduction in debris extrusion may contribute to a decreased risk of postoperative pain, as supported by literature suggesting that less extrusion is associated with fewer inflammatory responses in the periapical tissues (37). By choosing these systems, clinicians can reduce the risk of postoperative complications, especially in cases involving necrotic or inflamed tissues, where managing debris extrusion is crucial to avoid exacerbating symptoms.

It is worth noting the remarkable performance of the HyFlex EDM system, categorized as a 'single-file' rotary system, which yielded results comparable to those of reciprocating systems. This achievement can be attributed to its distinctive thermal treatment and the fact that it operates as a single-file system within a rotary framework. The thermal treatment likely enhances the file's flexibility and cutting efficiency (38) while the single-file design may minimize debris generation during the procedure. These features suggest that the HyFlex EDM system presents a balanced approach, incorporating the advantages of both rotary and reciprocating systems in terms of debris extrusion and instrumentation time. These findings align with the literature regarding instrumentation time but contrast with respect to the amount of extruded debris (39). While our in vitro study sheds light on the potential for debris extrusion, it's important to acknowledge that clinical conditions may mitigate some of these effects. In many instances, patients may not even present symptoms associated with debris extrusion (2). Nevertheless, clinicians should exercise caution, especially when dealing with contaminated canals or cases linked to lesions, as such scenarios may heighten the risk of postoperative complications (1). Therefore, the choice of the system should be tailored not only to the clinical context but also to the operator's proficiency with the system.

The time factor in our study was evidently and understandably linked to the number of instruments in the system (40). However, it's crucial to emphasize that time should not be the sole determinant in selecting an endodontic system. For example, Protaper Ultimate, despite having the longest mean instrumentation time among all systems, was also among the least likely to extrude

debris. This implies that investing a few extra seconds or minutes in instrumentation can lead to a cleaner and potentially more successful outcome. Moreover, the longest time in our study (194 seconds) is clinically negligible, equating to slightly over 3 minutes of instrumentation. In alignment with current guidelines advocating for a "slow endo" approach, there's no need to rush the instrumentation process. While our study examined the time factor, we did so primarily to gather additional data. When applied to clinical practice, it's of paramount importance to remember that quality should take precedence over speed. Additionally, we acknowledge that our decision to investigate the time factor stemmed from our understanding that it might reveal potential challenges for operators when working with a system and guide clinicians regarding this aspect.
While this study provides valuable insights into the performance of various endodontic file systems, several limitations should be acknowledged. First, all procedures were carried out by a single experienced operator. Although this approach ensured consistency, it may introduce bias due to personal preferences or subtle variations in technique, which could affect the generalizability of the results. Additionally, the study was conducted in a laboratory setting on extracted teeth, which may not fully replicate the complexities encountered in clinical practice, such as patient-related factors and varying anatomical challenges. Finally, only the mesiobuccal canals of mandibular molars were instrumented, potentially limiting the applicability of the findings to other tooth types and canal configurations. These limitations should be considered when interpreting the results and applying them to clinical practice.

Conclusion

The current study provides a detailed comparison of debris extrusion and instrumentation time across a range of endodontic file systems. These finds underline the importance of careful system selection based on specific procedural requirements and desired clinical outcomes. The study offers evidence-based guidance that can assist clinicians in selecting endodontic file systems that balance efficiency with procedural cleanliness. This tailored approach is critical for optimizing patient outcomes, as it takes into consideration the specific advantages and potential drawbacks of each system in relation to the clinical context.

Clinical Relevance

The extrusion of debris may result in postoperative pain, flare-ups, and the necessity for retreatment, thereby affecting the patient's experience and the prognosis of endodontic treatment. Research in this field facilitates the development of more effective clinical protocols, ensuring patient safety and improved outcomes.

Conflict of Interest

The authors declare that they have no competing interests.

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Ethics Approval

After obtaining approval from the local Research Ethics Committee (opinion no. 5.731.282).

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ORIGINAL ARTICLE

A comparison in the efficacy of 3D-printed guides versus traditional endodontic access: an ex-vivo study

ABSTRACT

Aim: *This ex-vivo study aimed to evaluate the accuracy and efficacy of digitally designed 3D-printed endodontic guides (3DGs) in achieving a conservative endodontic access preparation on maxillary molars compared to a traditional endodontic access (TRAD).*

Methodology: *Eighty extracted maxillary molars were divided into two groups: (1) TRAD access and (2) 3DG access. Two operators with varying levels of experience performed both approaches. Time allocated to perform each procedure was recorded. Volumetric analysis was done by comparing data from the pre- and the post-operative CBCTs.*

Results: *Both operators with the 3DG cavity access located 100% of the canals present, while the TRAD groups missed 30.76–81.81% of second mesiobuccal canals. Time required and substance loss were significantly lower in the 3DG group vs. the TRAD group.*

Conclusions: *Within the limitations of this study, the use of an endodontic 3DGs helped in preserving a significantly more dental structure in significantly less time.*

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Introduction

The first step towards the treatment and prevention of apical periodontitis is to establish access to the root canal system. The objective is not only to localize all the canals but also to remove the minimally necessary dental structure to maintain the structural stability of the crown (1). Excessive removal of dental structure during this process may lead to decreased resistance to fracture and a significant weakening of the future restoration(2,3). In addition, restricted visibility due to an incorrect access cavity preparation potentially results in missed anatomy, increased strain on instruments, inadequate disinfection and cleanse of debris and smear layer removal (4, 5).

Root fractures and missed anatomy such as untreated second mesiobuccal (MB2) canals are two major causes of failed endodontic therapy (6, 7). The reported incidence of missed canals in upper first molars ranges from 41.30% to 46.50% (8). On the other hand, the presence of MB2 canals varies from 30% to 90%, but the percentage of clinically identified MB2 canals is lower than those reported in vitro due to the presence of coronal calcifications in those canals (9-12). New technologies such as the implementation of digital dentistry and cone beam computed tomography (CBCT) helped significantly overcome these challenges (13, 14). In 2010, Clark and Khademi (1) introduced the term "conservative access cavity" (CAC) which aimed to achieve a better endodontic, restorative and prosthodontic structural preservation of dentin. This approach shifted from the traditional access cavity (TRAD), where there was an emphasis on achieving straight line access to the initial curvature of the canals or the apical part of the canal. The CAC starts from the central fossa and extends only as necessary to locate the canal orifices, preserving the pericervical dentin and part of the pulp chamber roof (15).

Recently, there have been meaningful advancements in the digital applications and 3D-printing in Endodontics. Reports on the implementation of 3D-printed guides (3DGs) to provide a CAC and to facilitate the location of root canals have been published in the last few years (15-19). However, the majority of these articles used 3D-printed replicas of anterior teeth, while a low number of studies used human molars and evaluated procedural time.

Therefore, the aim of this ex-vivo study was to evaluate the accuracy of a digitally planned 3DGs on the localization of root canals, the reduction in procedural time and the preservation of dental structure in human maxillary molars. The secondary objective was to evaluate the influence of operator experience using these approaches. To test this, the null hypothesis was that there is no significant difference in the accuracy and efficacy between these two approaches.

Material and methods

Ethical aspects

This prospective clinical study was conducted at the Faculty of Dentistry, Complutense University of Madrid. The study followed the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines (20). All procedures performed in this study were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The research protocol was approved by the ethics committee of the CEIC Hospital Clínico San Carlos (Madrid, Spain) with the registration number 23/554-E.

Sample size calculation

The sample size was estimated based on a previous study (21) that compared CAC, TRAD, and point endodontic access cavities, allocating 20 extracted teeth per group. Accordingly, for the analysis with alpha (α)=0.05, a heterogeneity of 50%, and 95% statistical testing power, a total of 67 teeth were indicated as the ideal size re-

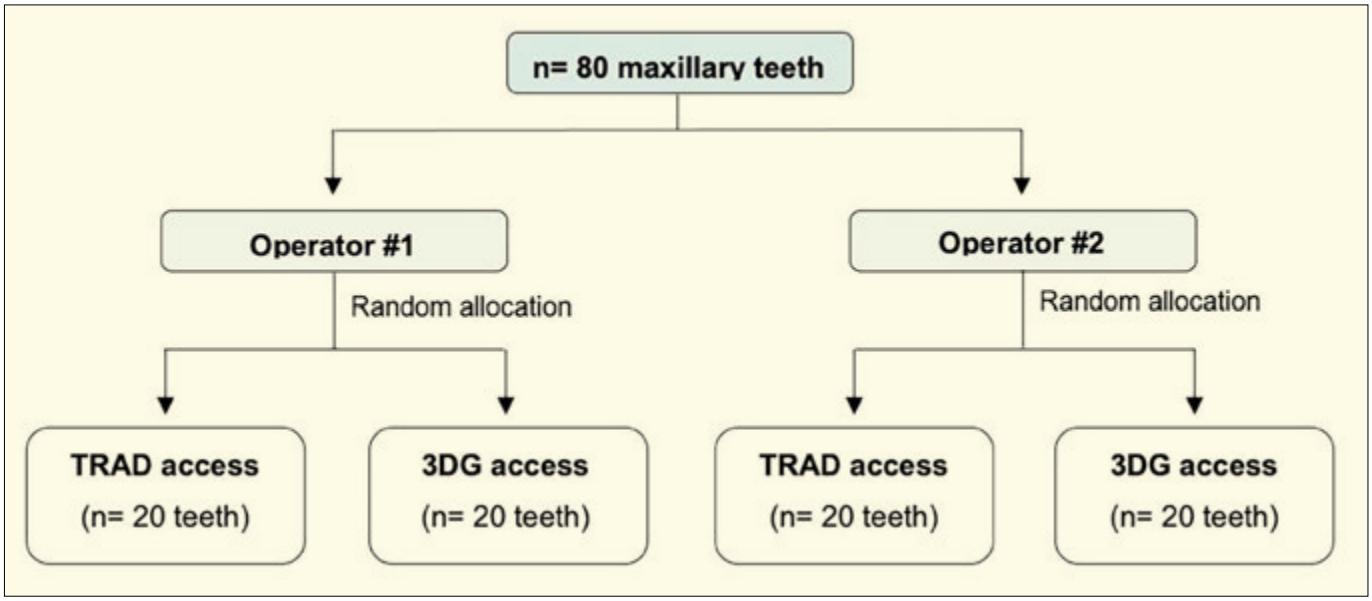

Figure 1
Study distribution (TRAD., traditional access cavity group; 3DG., 3D-printed guide access cavity group).

quired for observing significant differences. Twenty teeth were allocated for each testing group.

Study design

This experimental laboratory study was performed on extracted maxillary teeth. Eighty human maxillary first and second molars were collected from the Department of Dental Clinical Specialties at the Complutense University of Madrid, Spain. Two operators with different levels of experience in endodontic treatments performed the procedures. Operator #1 was a general dentist with over 10 years of experience, including root canal treatments in anterior teeth and premolars, and occasionally on maxillary or mandibular first molars. Operator #2 was a third-year endodontic resident with previous endodontic training. Each operator worked on 40 teeth randomly allocated in two groups: one group where a TRAD access cavity (n= 20 teeth) was performed and another group using 3DGs (20 teeth) (Figure 1) for access cavity preparation. The teeth were mounted in a human skull to mimic the anatomical structures encountered during the image acquisition. A custom-made jig using Vinyl Polysiloxane (Aquasil Easymix Putty, Dentsply Sirona, York, PA, USA) was used to replicate the pre- and post-CBCT imaging position (Figure 2).

Pre- and postoperative CBCT (pre-CBCT and post-CBCT, respectively) images were acquired to evaluate the amount of tooth structure removed during endodontic cavity access preparation. CBCT scans were taken using a 3D Accuitomo (Morita Corp., Irvine, CA, USA) with scan parameters set to 90 kVP and 7.0 mA, at a field of view of

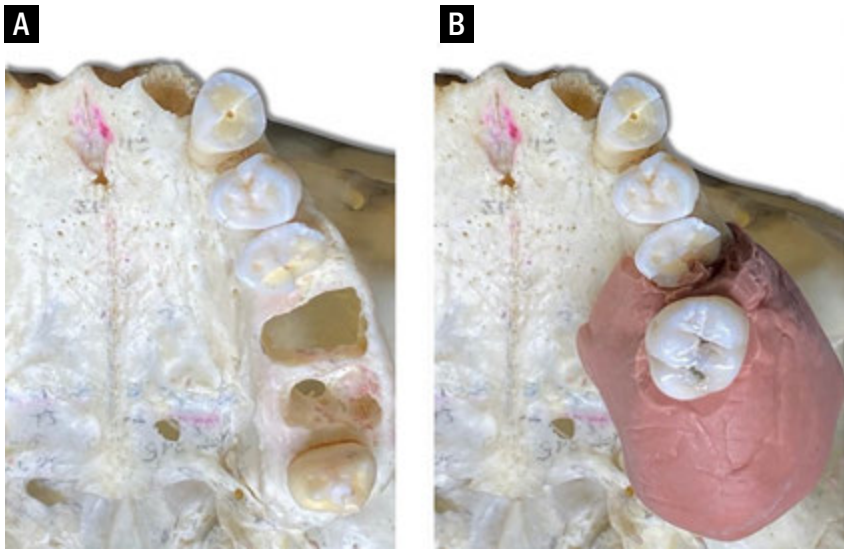

Figure 2
A) Occlusal view of the skull with the socket to receive the sample teeth. **B)** Custom made jig placed positioned in the skull.

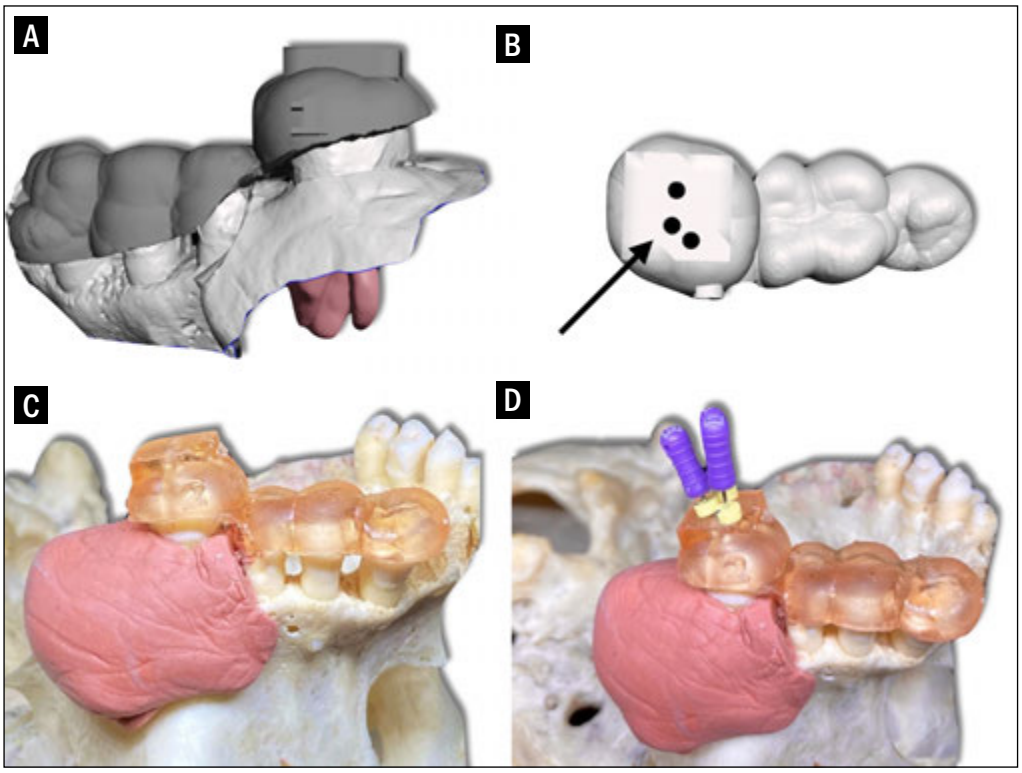

Figure 3
A) 3DG positioned on the maxillary teeth. **B)** Occlusal view of the 3DG (*black arrow indicates the 3 circular openings where canals are located). **C)** 3DG positioned in the maxillary teeth. **D)** View of #10 K-files through the circular openings demonstrating the accuracy of the 3DG.

140x100 mm at the "high resolution" setting (100 microns voxel size). The CBCT scans were not available for the operators before the access cavity procedures. Periapical radiographs were available for operative reasons as needed. The CBCT images were evaluated by a radiologist and by independent evaluator after the post-op scan was completed.

The design and fabrication of the 3DGs were carried out by an investigator not involved in the access cavity preparation. The protocol implemented for the design and printing was as follows: A digital impression of the teeth using an intraoral scanner was taken (Cerec Omnicam, Dentsply Sirona, Bensheim, Germany) to create the stereolithographic (STL) file of the anatomy of the occlusal surfaces. The digital images of the CBCT were segmented in an editor for Digital Imaging and Communication in Medicine (DICOM) files, and different STL files were created (22). One file included the anatomy of teeth and bone, and a second file presented the segmentation of teeth individually without bone tissue present. These STL files were merged in a 3D triangular mesh editor software (MeshLab, ISTI-CNR, Pisa, Italy). After the merging process, the STL files were introduced into another 3D mesh editor software (Meshmixer, Autodesk Inc., Ontario, Canada) for the final design of the digital endodontic guides based on the canal location information obtained from the CBCT images. The software used for the entire digital planning are freely accessible (Open source). The 3DG was designed so that the distance from the entrance of the canal to the circular orifice on the guide matched the length of the drill to a reference point. Then, the 3DG was printed in a 3D printer (Form2, Formlabs, Somerville, MA, USA) using a Food and Drug Administration (FDA) approved resin (Dental SG Resin, Formlabs, Somerville, MA, USA) (Figures 3 and 4).

The skull was positioned in the dental chair to mimic a clinical environment. Operators were allowed to use dental loupes (4.5x magnification) or operating microscope (0.5x magnification) as a form of magnification, according to their preferences during the cavity access procedures. Even

Figure 4
Occlusal view of one of the 3DGs used in the study showing the circular windows that correspond with each canal orifice location.

though the choice was made by each operator, Operator #1 mostly used dental loupes and Operator #2 used the operating microscope exclusively. An endodontic cassette and sodium hypochlorite 0.5% with 27-gauge needles were provided to the operators. Ultrasonic tips were also allowed to supplement the location of the canals if needed.
For the 3DG groups, the guides were positioned on the occlusal surface of the extracted teeth and their fit was carefully checked. When the proper fit was confirmed, cavity preparations were performed with a #2 round bur following the circular openings of the guides where the canal orifice will be ultimately reached. This created individual circular accesses on top of each canal orifice while the rest of the roof of the pulp chamber was untouched. Then, the 3DG was removed and the cavity access was completed using an Endo Z bur following the external outline of the orifices. In the TRAD group, standard access cavity preparation was carried out by the operators using their desired high-speed burs (#4 and 6 round burs for the initial access, and Endo Z burs to refine access cavity preparation) and ultrasonic tips as an adjunct for the localization of the canals.

Measurement of study variables
Localization of root canal orifices and procedure time
Time allocated to perform the cavity access was recorded and stopped when all canals were located and negotiated by a #10 file or if the operator decided that there is no other canal or is too calcified to negotiate.

Dental substance loss
After the access cavities were performed, a post-CBCT image was obtained for each tooth and dental substance loss analysis in mm^3 were obtained. The substance loss was defined using the following formula:
Substance loss = pre-CBCT volume – post-CBCT volume
The pre-CBCT volume was defined as the total volume of the tooth minus the pulp volume. The post-CBCT volume was defined as the coronal volume minus the preparation volume. The analysis was performed by a radiologist using CoDiagnostiX software (Dental Wings, Montreal, Canada).

Statistical Analysis
The descriptive analysis of the data was calculated using Numbers version 10.0 (6748). Data was entered manually, and statistical significance was set to an α of 0.05. T-test was performed to determine if there was any significant difference between experimental groups.

Results

Localization of root canal orifices
The two operators in the 3DG group were able to locate and negotiate all canals present in the sample teeth, including all MB2 canals. In the TRAD groups Operator #1 set of teeth had 11 MB2 present on the CBCT, from which 9 were missed (81.81%). Operator #2 set of teeth presented 13 MB2 canals, and the operator was not able to find 4 of them (30.76%). There was a statistically significant difference on the location of MB2 canals between 3DG and TRAD groups ($P<0.05$).

Procedure time
The overall mean treatment time required to perform TRAD access was 25.03 ± 5.89 min. The mean treatment time required to perform the TRAD access for Operator #1 was 30.54±2.68 min and for Operator #2 was 19.52±1.32 min ($P<0.0001$). The overall mean treatment time required to perform the 3DG access was 16.98±1.63 min. The mean treatment time required to perform the 3DG access for Operator #1 was 18.13±1.22 min and for Operator #2 was

Table 1

Treatment time required to perform the TRAD access vs. 3DG access: Comparison between operators

	TRAD Access (min)	3DG Access (min)	P-value
Operator #1	30.54±2.68	18.13±1.22	P<0.0001***
Operator #2	19.52±1.32	15.83±1.13	P<0.0001***
T-test	P<0.0001***	P<0.0001***	
Overall	25.03±5.89	16.98±1.63	P<0.0001***

*=P<0.05, **=P<0.01, ***=P<0.001.

Table 2

Comparison of dental substance loss between the TRAD access vs. 3DG access, and between operators

	TRAD Access (mm^3)	3DG Access (mm^3)	P-value
Operator #1	251.41±18.93	121.28±12.75	P<0.0001***
Operator #2	129.45±14.41	112.03±9.54	P<0.0001***
T-test	P<0.0001***	P=0.0133***	
Overall	190.43±60.98	116.66±4.63	P<0.0001***

*=P<0.05, **=P<0.01, ***=P<0.001.

15.83±1.13 min (P<0.0001). There was a significant difference in the amount of time needed to perform a cavity access when the TRAD access was compared to the 3DG access method (P<0.0001) (Table 1).

Dental substance loss

The overall mean access volume loss for the TRAD access was 190.43±60.98 mm^3. The mean access volume loss for the TRAD access for Operator #1 was 251.41±18.93 mm^3 and for Operator #2 was 129.45±14.41 mm^3 (P<0.0001). The overall mean access volume loss for the 3DG access was 116.66±4.63 mm^3. The mean access volume loss for the 3DG access for Operator #1 was 121.28±12.75 mm^3 and for Operator #2 was 112.03±9.54 mm^3 (P=0.0133). The T-test determined that the substance loss in the 3DG group was significantly reduced compared to the TRAD group (P<0.0001) (Table 2).

Discussion

The results of the present study showed that endodontic access using a 3DG presents a significant reduction in substance loss, decreased operating time, and improved MB2 location rates.

The location of the MB2 canals was greatly improved with the use of 3DGs. In this sense, Operator #1 localized a lower number of MB2 canals compared to Operator #2 (81.81% vs. 30.76%, respectively; P<0.05). Both operators used magnification (loupes or dental operative microscope). The presence of MB2 was determined by the preoperative CBCT, but this information was not shown to the Operators pre-operatively. Studies on methods to aid in the location of MB2 found that magnification greatly improves the detection of the MB2 (23, 24). Other studies showed that even though magnification improves the frequency of MB2 canal location, there is no significant differences between the use of loupes vs. microscope (25). Another factor that might have contributed to the differences on the location rates of MB2 between operators could be the previous experience in Endodontics of Operator #2 and the use of ultrasonic tips during the search of the MB2 (26). The use of the CBCT volume data is a useful tool to determine the amount of dental structure preserved before and after inter-

ventions with minimal deviation (27). The present study showed a significant difference in the overall dental structure loss during the cavity access between TRAD access and 3DG access (190.43±60.98 mm^3 vs 116.66±4.63 mm^3, respectively; $P<0.0001$). Our results are in accordance with the study by Connert et al. (28) showing a significant difference in substance loss between the 3DG group vs. the TRAD group in anterior teeth. Similarly, an ex-vivo study conducted by Loureiro et al. (29) found that the 3DG access significantly reduced the dental structure loss compared with the TRAD group in extracted upper molars. However, there was no difference between these groups when evaluating mandibular incisors. The preservation of the dental structure is known to positively impact the long-term fracture resistance of endodontically accessed teeth (30, 31).

To ensure the efficiency of the procedure and patients' comfort in root canal treatment, a reduction of procedural time is beneficial. The results in our study show that there is a significant improvement in overall time needed to perform an access cavity when using 3DGs compared to the TRAD group, which saved an average of 8.05 min in procedural time ($P<0.0001$). These results are in accordance with a previous study which showed a reduction in procedural time of 10.50 min when 3DGs were used compared with a "free-hand" group (28). Our study did not take into account the additional time required for scanning the anatomy of the patient, the computer design and the fabrication of the 3DGs. Nevertheless, this additional planning time could be justified by the overall reduction in procedural time, preservation of dentin and location of canal orifices. On the other hand, 3DGs have been proven useful to aid in the location of calcified canals. Several case reports showed successful results in maxillary (29, 32-35) and mandibular incisors, (35), maxillary premolars (37), and maxillary, (37, 38) and mandibular molars (39).

The majority of the studies available in the literature have used software exclusive for dental implant planning. This is done by simulating an implant placement on a root canal and changing the parameters of the implant to match the diameter and length needed for the burs and sleeves used. In addition, most software, if not all, are subscription-based or require a one-time payment. In the present study, the entire digital workflow for the guide design used open-source software, freely accessible for any clinician.

Some of these software (Meshmixer and Meshlab) are focused on 3D editing in general, therefore, there are more possibilities at hand in terms of the design of the 3DGs. However, it should be noted that these software do not present specific dental settings or digital dental tools, therefore they are not as user-friendly as the dental software programs.

Despite the above-mentioned advantages, the use of 3DGs for endodontic treatments presents multiple limitations. First, 3DGs are not suitable for emergency scenarios due to pain or infection when the tooth in question requires immediate treatment. Designing and printing these guides takes a significant amount of time and are only indicated for cases when the patient will be seen on a different date after the initial consult. In addition, CBCT imaging is essential for it, however, radiographic artifacts might compromise the accuracy of the data and could negatively influence the superimposition of the DICOM files with the surface scans files from the intraoral scanner. This is due to the beam hardening artifacts created by dental implants and/or metallic restorations such as full-coverage crowns (40, 41). Nevertheless, there are techniques available that facilitate the superimposition of the images by adding fiducial markers in both the CBCT and intraoral scan when metallic restorations are present (42).

Furthermore, in cases where calcified canals are present, 3DGs cannot reach past a curvature because the drill or bur is limited to an apico-coronal motion. If the canal presents a curvature before the target point, the use of these guides should be avoided to prevent the risk of perforation. Also, clinicians need to take into consideration that the thickness of

the guide and the sleeve height reduces the inter-occlusal space available for the instruments. In posterior cases with limited mouth opening, the use of 3DGs would not be feasible. Nevertheless, the use of a sleeveless guide would help to reduce the vertical space occupied by the guide (33). In addition, conservative access cavities performed using the 3DGs could result in the accumulation of debris in the potential undercuts of the roof of the pulp chamber, which might serve as a source of a persistent infection (43).

This study also presents limitations. The dental substance loss analysis was performed using CBCT imaging. Even though this type of imaging is acceptable for this type of evaluation, a Micro-CT analysis would have provided more accurate data when the pre- and postoperative scans were taken. Also, the patients' age from the extracted teeth used in the sample could not be determined. This can significantly affect the difficulty of canal localization and negotiation in different age groups. Older teeth usually present narrower pulp chambers and higher prevalence of calcified canals, increasing the difficulty of the access cavity and location of the canals.

Our study demonstrated significant differences in the accuracy and efficacy of achieving conservative endodontic access preparation on maxillary molars between the digitally designed 3D-printed endodontic guides (3DGs) and traditional endodontic access (TRAD). Therefore, we reject the null hypothesis that there is no significant difference between these two techniques.

These findings suggest that 3D-printed endodontic guides may offer a more effective alternative to traditional methods for achieving conservative access in endodontic procedures. Further studies are needed to evaluate the feasibility of these guides in clinical practice. In addition, the current digital workflow is convoluted for routine use. Newer and more user-friendly digital workflows need to be investigated to broaden the use of the 3DGs in Endodontics.

Conclusion

Within the limitations of this ex-vivo study, the use of 3DGs leads to significant reductions in the amount of tooth structure removed and procedural time when performing endodontic access cavities, regardless of the operator's experience. In addition, the use of these guides shows significantly better location rates of the MB2 canal compared to a non-guided approach.

Clinical Relevance

The use of 3DGs leads to a significant reduction in the amount of tooth structure removed and procedural time when performing endodontic access cavities, independently from the experience of the operator.

Conflict of Interest

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

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SYSTEMATIC REVIEW

The treatment options for the management of internal root resorption

ABSTRACT

Aim: *This systematic review aimed to analyze and compare the outcomes of reported treatment options for managing IRR in mature teeth.*
Methodology: *Literature search was conducted using the PubMed, Wiley Online Library and EBSCOhost databases. Clinical trials, case reports/series, which were conducted over a nine-year period describing methodology of IRR treatment were included.*
Results: *From 38 cases of twenty included manuscripts, 19 – described REP, 19 – entire root canal treatment for the management of IRR. The eligible studies showed low risk of bias. The clinical symptoms of causative tooth such as pain or sinus tract, if was related, disappeared during follow up period. Bone destruction healing process was assessed during radiological evaluation despite the applied IRR management method. The resorption area reduced in size or was repaired by mineralized tissue formation in all cases treated by REP.*
Conclusion: *Despite the differences in treatment protocols analyzed for managing of IRR, the outcomes of root canal treatment and REP were comparable and favorable. Based on the limitations of this review, both methods are applicable for treating IRR after evaluating the specific clinical situation in practice.*

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Introduction

Internal root resorption (IRR) is a process that occurs in the dental pulp in response to a stimulus, usually an infection. This leads to the destruction of dentine within the root canal space (1). The pathogenesis of IRR is primarily characterized by the activity of odontoclasts (2, 3). The formation of inflammatory IRR starts when the pulp tissue cells and layer of predentin are damaged with a presence of a continuous bacterial stimulation (4). Possible causes of IRR include traumatic injury, caries, endodontic infection, orthodontic treatment, and teeth whitening (2, 3). Scientific literature also describes other potential causes of IRR such as Herpes zoster virus, dens invaginatus, or idiopathic factors (2, 5). Regardless of the origin, IRR can be asymptomatic and may only be discovered through radiographic imaging. It can also present with symptoms of pulpitis or apical periodontitis if the root canal wall is perforated (3, 6, 7). Diagnosing IRR usually requires thorough radiological examination, including the assessment of cone beam computed tomography (CBCT) (8).

Various types of root resorptions potentially affect all anatomical groups of mature permanent teeth. These resorptions usually require different treatment planning strategies in contemporary endodontic practice (1, 6, 9). The progressive loss of dentin within the root canal space as along with possible bone destruction in the resorption site and/or periapically, presents a clinical challenge to select the appropriate treatment method for managing this process in a particular clinical situation. According to the published guidelines of European Society of Endodontology (ESE), the treatment options for managing IRR include root canal treatment with or without internal or surgical repair in case of perforation as well as tooth extraction (10).

Regenerative endodontic procedures (REP) have been identified as a potential option for managing IRR. However, there is currently a lack of strong evidence supporting this treatment method (10). The limited number of published results and heterogeneity of the methodologies pertaining to treatment of IRR highlight the need to analyze published clinical studies or case/case series reports concerning the outcomes of IRR treatment. By reviewing the different clinically recognized methods used to treat this condition, their effectiveness can be compared and the valuable information for clinicians and researchers be provided. Therefore, the objective of this systematic review was to analyze and compare the outcomes of reported treatment options for the managing IRR.

Materials and methods

Protocol and registration

The reporting of this systematic review was in relevance to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (11). The review was registered in an international prospective register of systematic reviews (PROSPERO) under the number CRD42024499151.

Focus question

The systematic review was conducted following the population, intervention, comparison, outcomes and study design (PICOS) question: Is the entire root canal treatment with(out) internal or surgical repair of any perforation (I) as effective as REP (C) evaluating clinical and radiological symptoms after the treatment of IRR with at least 12 months follow up period (O) in patients with diagnosed IRR in mature permanent teeth (P)? Study design (S) – case reports, case series reports.

Eligibility criteria and search strategy

The search of the articles was conducted throughout the databases of PubMed, Wiley Online Library, EBSCOhost and limited to English language. The selection of publications was carried out by electronic databases from the 1st of May 2023 until the 1st of February 2024. A detailed search of scientific electronic data was conducted independently by two investigators (RP, NS). The full keywords and

their combinations used for the search on each of the selected databases are presented in Table 1. The first (#1) search with keywords was based on the terms associated with internal root resorption. Subsequent searches (#2, #3, #4) were conducted using keywords related to potential internal root resorption treatment methods using various combinations of the Boolean operators "AND" and "OR". The final search (#5) integrated a combination of previous four searches results. Two investigators (RP, AK) independently analyzed the titles and abstracts of the studies that met eligibility criteria. Duplicate records were eliminated, and the remaining articles were screened according to the inclusion and exclusion criteria.

Inclusion criteria included: 1) case reports or case series with the pathology of IRR in human permanent mature teeth and the treatment of IRR described; 2) postoperative clinical and radiological evaluation of the treatment of IRR after at least 12 months presented; 3) studies published as a full article in English.

Exclusion criteria were: 1) case reports where the strategy of the treatment was tooth extraction; 2) review articles or Meta-analyses, animal, *in vitro* studies; 3) articles regarding diagnostics methods in cases of IRR.

The full texts were then evaluated according to the eligibility criteria by the same group of authors. Cohen's Kappa index (κ) was used to assess inter-rater reliability between the reviewers (RP, NS) during the study selection process. This value was computed based on the contingency table of the reviewers' decisions, with interpretations following standard guidelines to ensure reliability of the review process (12). Cohen's Kappa value of this review complied with substantial agreement ($\varkappa = 0.76$, $\varkappa > 0.61$). Any disagreements were resolved by discussion with the second and fourth authors, a senior researcher (GL, NS). The selection process of the articles, the excluded studies and the reasons for exclusion are presented in PRISMA flowchart (Fig.1). The relevant articles published from 1st of January, 2015 up to 1st February, 2024 in accordance with keywords were selected.

Data extraction process

The extracted study characteristics included: the patient's and tooth number; the location of the resorption; presence of root perforation; clinical symptoms and radiological findings; treatment steps and materials used; the time of follow-up; the treatment outcomes. The success of managing IRR was assessed based on clinical symptoms and radiological changes during the follow-up period (13). A case was considered favorable when the patient's condition was asymptomatic after treatment, the radiographs revealed absent or decreased in size periapical lesion, no deterioration or appearance of a new defect were detected, and possible mineralized tissue formation was observed in the resorption area. Conversely, a case was considered as unfavorable if one of the following criteria was present during follow up: the patient experienced clinical symptoms (e.g. sinus tract); the radiologically visible lesion of periapical tissues has appeared or remained/increased in size; the increased resorption area was evident in radiogram.

Risk of bias assessment

The risk of bias within the case reports and case series was assessed by a tool based on established criteria, including modifications from the Pierson criteria, Bradford Hill's criteria, and the Newcastle-Ottawa Scale (14). This tool evaluated methodological quality across eight items grouped into four key domains (Table 2): selection, ascertainment, causality, and reporting. Each domain addressed specific aspects of study design and reporting that may influence the reliability and applicability of the findings and was presented as questions with binary responses to indicate whether each item suggests bias. The quality of the report was classified as low risk of bias if all five criteria were met, moderate if four criteria were met, and high risk of bias if three or fewer criteria were met (15). All incorporated articles were subjected to an extensive evaluation by critical appraisers.

Table 1

Strategies for database search

Database	Search Strategy
PubMed	#1 (root resorption) OR (internal root resorption)) OR (internal root destruction)
Wiley Online Library	#2 (internal root resorption treatment) OR (internal root resorption management) AND (root canal treatment)) OR (pulp extirpation) OR (endodontic treatment)) OR (revascularization) OR (regenerative endodontic procedures)) OR (revascularization)
EBSCOhost	#3 (internal root resorption treatment) OR (internal root resorption management) AND (root canal treatment) OR (pulp extirpation) OR (endodontic treatment) OR (revascularization)) OR (regenerative endodontic procedures) OR (revascularization)
	#4 (internal root resorption treatment) OR (internal root resorption management) AND (root canal treatment) OR (pulp extirpation) OR (endodontic treatment) OR (revascularization) OR (regenerative endodontic procedures) OR (revascularization)
	#5 #1 OR #2 OR #3 AND #4

Results

Quality assessment

Twenty studies (16-35) were included and evaluated according to the checklist for case reports and case series as seen in Table 2. The overall risk of bias among the incorporated manuscripts was assessed. One case report was rated as moderate quality, while the remaining 17 articles were considered high-quality reports. As all articles met most of the criteria of the checklist questions it was concluded that the selected articles for this review are of good quality and the risk of bias is low.

Question n 1. Does the patient(s) represent(s) the whole experience of the investigator (center) or is the selection method unclear to the extent that other patients with similar presentation may not have been reported?

Question n 2. Was the exposure adequately ascertained?

Question n 3. Was the outcome adequately ascertained?

Question n 4. Were other alternative causes that may explain the observation ruled out?

Question n 5. Was there a challenge/rechallenge phenomenon?

Question n 6. Was there a dose–response effect?

Question n 7. Was follow-up long enough for outcomes to occur?

*Question n 8. Is the case(s) described with sufficient details to allow other investigators to replicate the research or to allow practitioners make infer*ences related to their own practice?

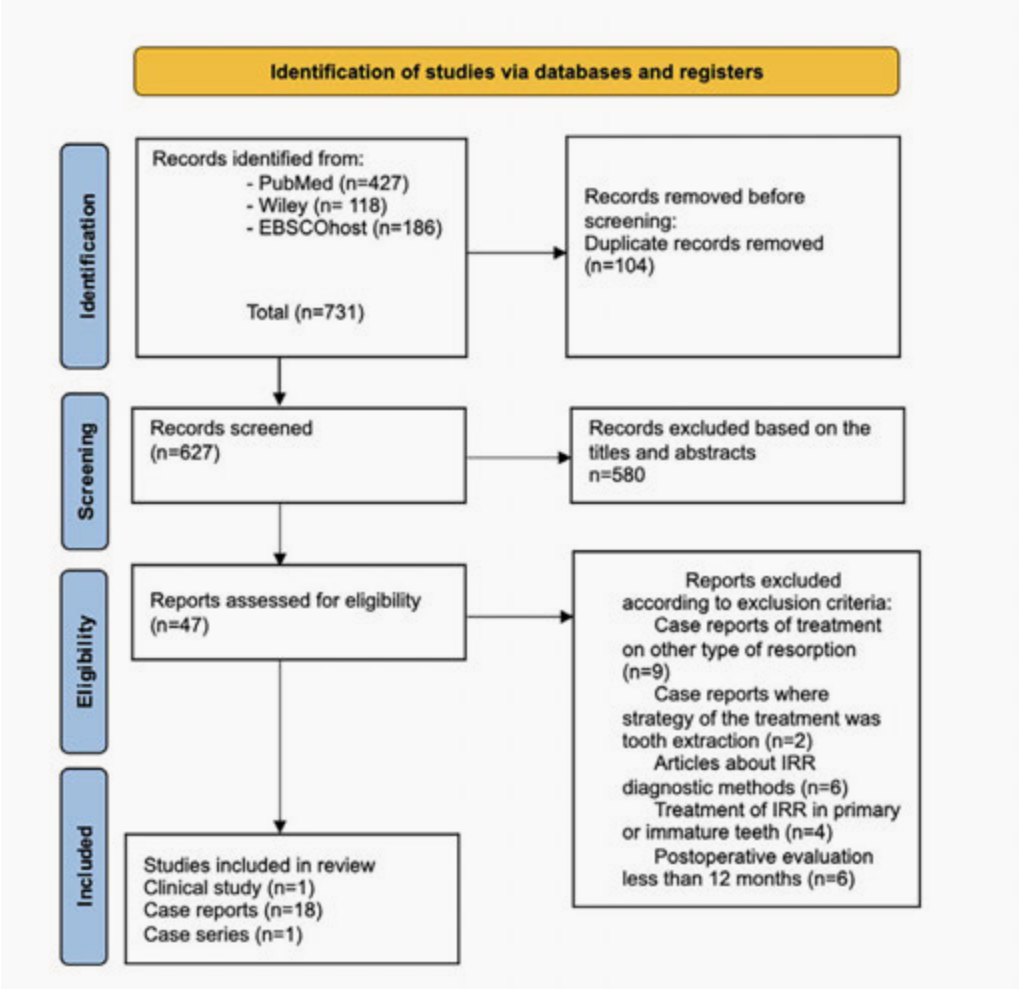
Literature search process

The initial identification resulted in 731 articles from the PubMed, Wiley Online Library and EBSCOhost databases. After the screening and evaluation of inclusion/exclusion criteria 20 studies were included into review: 18 case reports (22 cases), and 2 case series studies (16 cases). Complete selection process of the scientific literature for this review is illustrated in PRISMA flowchart (Fig. 1).

Characteristics of the included studies

All the selected articles were divided according to the treatment method for managing IRR: root canal treatment or REP. In this systematic review, 38 teeth (35 patients) diagnosed with IRR were analyzed. Three patients had 2 teeth with this pathology (21). The diagnoses were confirmed on the basis of radiological data, for 29 teeth, diagnosis was confirmed by CBCT (18-23, 26-30, 32, 33, 35) and for the remaining 9 teeth, diagnosis was

Figure 1
PRISMA flowchart outlining the search strategy



confirmed on the basis of periapical radiographs (16, 17, 24, 25, 31, 34). The characteristics of the all included cases (16-35) are presented in Table 3. Symptoms, treatment procedures provided for the management of IRR and the outcomes of the REP or root canal treatment are presented in Table 4 and Table 5, respectively.

Regenerative endodontic procedures for the management of internal root resorption

The treatment protocols for IRR varied among authors (Table 4) when treated with REP. The sodium hypochlorite (NaOCl) was used in all cases for irrigation of root canals with IRR, but the concentration of it ranged from 1% to 5.25% in different cases. Some authors used saline (16, 17, 21), distilled water (18) or 0,1% chlorhexidine (16) in addition to NaOCl. Ethylenediaminetetraacetic acid (EDTA) was used for additional irrigation before obturation in 17 teeth out of 19 teeth treated by REP (17-21). The instrumentation of the root canals also varied. In 4 treated teeth, the coronal part of the root canal was instrumented until/with resorption (16, 19, 20), while three authors (15 treated teeth) reported instrumentation of the entire length of the root canal (17, 18, 21).

More than one visit treatment was applied in almost all (18 teeth) of the analyzed cases (16-18, 20-23, 25-28, 30-35). Calcium hydroxide ($Ca(OH)_2$) was used as intracanal medication between visits in most of the treatment protocols (16-18, 20, 21). The triple antibiotic paste for dressing the root canal was used only in one of all analyzed cases (17). The duration of intracanal medication with $Ca(OH)_2$ ranged from 2 weeks to 4 years. The root canal was temporarily sealed with $Ca(OH)_2$ for 2 to 4

Table 2

Risk of bias assessment of included studies

First author/Year	Question 1		Question 2		Question 3		Question 4		Question 5		Question 6		Question 7		Question 8		Risk of bias
	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N	
Ebeleseder&Kqiku (2015) (16)	+		+		+		+		+			+	+		+		low
Saoud et al (2016) (17)	+		+		+		+		+			+	+		+		low
Kaval et al. (2018) (18)	+		+		+		+		+			+	+		+		low
R. Pereira da Costa et al. (2020) (19)	+		+		+		+		+			+	+		+		low
Arnold M. (2021) (20)	+		+		+		+		+			+	+		+		low
Nageh et al. (2022) (21)		+	+		+		+		+			+	+		+		moderate
Bendyk-Szeffer et al. (2015) (22)	+		+		+		+		+			+	+		+		low
Ramazani M et al. (2016) (23)	+		+		+		+		+			+	+		+		low
de Souza SN et al. (2017) (24)	+		+		+		+		+			+	+		+		low
Subay et al. (2018) (25)	+		+		+		+		+			+	+		+		low
Mehra N. et al (2018) (26)	+		+		+		+		+			+	+		+		low
Patni PM. et al. (2018) (27)	+		+		+		+		+			+	+		+		low
Yildirim S. et al. (2019) (28)	+		+		+		+		+			+	+		+		low
Fráter M et al. (2020) (29)	+		+		+		+		+			+	+		+		low
Tavsan O. et al. (2020) (30)	+		+		+		+		+			+	+		+		low
Pérez-Alfayate R. et al. (2020) (31)	+		+		+		+		+			+	+		+		low
Mandviwala DK. et al. (2022) (32)	+		+		+		+		+			+	+		+		low
Pawar S. et al. (2022) (33)	+		+		+		+		+			+	+		+		low
Riyahi AM. (2022) (34)	+		+		+		+		+			+	+		+		low
Gupta G. et al. (2022) (35)	+		+		+		+		+			+	+		+		low

Table 3

Characteristics of the studies

Characteristics	Number
Patients	35
Teeth	38
Age of the patient	
<18 years	10
19-30 years	18
31-50 years	4
51<years	2
No mention	1
Tooth type	
maxillary incisors	31
maxillary molars	1
mandibular incisors	2
mandibular molar	2
mandibular premolar	1
maxillary canine	1
Location of resorption (parts of the root)	
coronal	10
middle	12
apical	8
coronal and middle	4
middle and apical	4
Clinical/radiological symptoms	
root perforation (bone destruction in resorption area)	11(10)
pain and tenderness to percussion	26
sinus tract	>5
Sensitivity test	
negative	15
positive	3
no mention	20
periapical lesion	21
IRR diagnosted by	
periapical radiographs	9
CBCT	29

weeks by two authors (14 teeth) (17, 21), and for more than two year – by one author (2 teeth) (16). However, one author treated IRR in one visit (19) (Table 4).

Mineral trioxide aggregate (MTA) was used as the cement for obturation of the root canals in all of the analyzed cases when IRR was treated applying REP. Five authors (6 teeth) indicated that they used MTA to fill the coronal part of the root up to the resorptive lesion (16-20). In 3 treated teeth a blood clot was created before filling the coronal part of the root (17, 18, 20). The blood clot formed after bleeding, which was induced by the sterile instrument from the periapical tissue (2 teeth) (17, 18) or from tissues in the area of resorption (1 tooth) (20). In the clinical study, the authors used injectable platelet-rich fibrin (i-PRF) for REP and placed MTA underneath the cementoenamel junction (21). IRR with root perforation was present in 5 clinical cases treated by REP (16-20). The REP protocol for IRR treatment was similar in all of the analyzed cases, regardless of the presence of perforation.

Procedures for managing internal root resorption during root canal treatment

Nineteen teeth with IRR included in this review were treated by conventional root canal treatment with or without surgical intervention (Table 5). The sodium hypochlorite (NaOCl) was used almost in all cases for irrigation of root canals with IRR, only one author did not specify the protocol of root canal irrigation (32). The concentrations of NaOCl used to disinfect the root canals varied from 1% to 5.25%. During five teeth treatment (23, 29, 33-35) only the NaOCl was used for root canal disinfection, whereas in other 13 cases (22, 24-28, 30, 31) other irrigating solutions in addition to NaOCl, such as saline (22, 26), 17% EDTA (22, 24, 27, 28, 30, 31), 10% citric acid (26), 2% chlorhexidine solution (27) were used.

Although four teeth without perforation of IRR were treated in a single visit (24, 29, 31, 34), most of the published treatment protocols included two or more visits root canal treatment (15 cases) (22, 23, 25-28, 30-33, 35). $Ca(OH)_2$ was used as intracanal medicament during these visits. The duration of intracanal medication varied from 7 days to 3 months (22-35).

The obturation protocols for root canals with IRR varied depending on the authors and clinical situation, such as the location of the IRR, or the presence of perforation. In all the cases analyzed, obturation was performed using hydraulic calcium silicate (HCS) based cements (22, 23, 25-32,

Table 4

Regenerative endodontic procedures for the management of internal root resorption and outcomes

	Criteria / Article	Amount of treated teeth	clinical/radiological symptoms				root canal disinfection	intracanal medicament, exposure time	
			root perforation (bone destruction in resorption area)	pain/ percussion/ sinus tract	sensitivity test Pre-op/ post-op	periapical lesion			
1	Ebeleseder &Kqiku (2015) (16)	2	Yes (N)	N/N	N/NM	No	3,5% NaOCl, saline, 0,1%CHX	mixture of CaOH and 0,1% CHX replaced in 3-6 months in period of 4 years	
			No	N/N	N/NM	No		mixture of CaOH and 0,1% CHX replaced every 6 months for 2 years	
2	Saoud et al (2016) (17)	1	Yes (P)	P/P	N/N	Yes	2,5% NaOCl, saline, 17%EDTA	CaOH for 2 weeks, triple antibiotic paste for next 2 weeks,	
3	Kaval et al. (2018) (18)	1	Yes (P)	P/P	N/N	No	1% NaOCl, 17% EDTA, distilled water	CaOH for 4 weeks, replaced for next 3 months	
4	R. Pereira da Costa et al. (2020) (19)	1	Yes (P)	N/P	N/NM	No	5.25%NaOCl, 17% EDTA	one visit treatment	
5	Arnold M. (2021) (20)	1	Yes (P)	P/N/sinus tract	N/N	Yes	3% NaOCl, 17% EDTA	CaOH for 2 weeks, replaced for 4 weeks	
6	Nageh et al. (2022) (21)	13	No	P (10)/P (10)/ some cases with sinus tract	NM/N	Yes (10), No (3)	1,5% NaOCl, 17% EDTA, saline	CaOH for 2-4 weeks	

P- positive; N -negative; NM- not mentioned; Pre-op- preoperative; Post-op- postoperative; CaOH- Calcium hydroxide paste; CHX - chlorhexidine solution; PA- periapical radiographs; CBCT- cone beam computed tomography.

34, 35), as well as gutta-percha and sealer (22, 24, 26, 30-34).

These obturation methods were either used in combination (7 teeth) (22, 26, 30-32, 34) or separately with the choice of either HCS (6 teeth) (23, 25, 27-29, 35), or gutta-percha with sealer (6 teeth) (24, 26, 30, 31, 33).

The HCS cements used for obturation of root canals or resorption areas in the analyzed cases included MTA (22, 25, 26, 28-31, 35) followed by Biodentine (27, 32), Calcium enriched mixture (CEM) cement (23), and Endosequence BC RRM Fast set putty (34) (Table 5). Six teeth (22, 23, 25, 26, 28, 33) of IRR treated by conventional root canal treatment presented perforation of the root in resorption area. In four of these treated teeth the MTA was used for root canal obturation (22, 25, 26, 28). This involved using MTA (two teeth) (25, 28) for entire obturation of the root canal, or in combination with gutta-percha, where MTA was used only for obturation of resorption area (two teeth) (22, 26). One study (1 tooth) reported using CEM cement to fill entire root canal space (23). In the remaining one case (33), the canal was sealed with a gutta-percha, and after surgical intervention, the resorption site was filled with Biodentine. Additionally, surgical treatment was

Table 4

Regenerative endodontic procedures for the management of internal root resorption and outcomes

	root canal obturation material	Instrumentation area	follow-up time	Diagnostic assessment		outcomes		
				Pre-op	Post-op follow-up	destruction of periapical tissues	bone destruction in the resorption area	resorption area
	MTA	Coronally to resorption area disinfection only	6 years	PA	PA	absent	absent	calcification
	MTA		4 years	PA	PA	absent	absent	calcification
	MTA	Full WL	19 months	PA	PA	decreased	decreased	reduced in size
	MTA	Full WL	2 years	CBCT, PA	CBCT, PA	absent	decreased	hard tissue formation
	MTA	Coronally to resorption area	5 years and 9 months	CBCT,PA	PA	absent	absent	mineralised tissue formation
	MTA	Coronally to resorption area	3 years	CBCT, PA	CBCT, PA	absent	absent	hard tissue formation
	MTA	Full WL	12 months	CBCT, PA	CBCT	decreased	absent	reduced in size

performed in four teeth, which involved removing the granulation tissue and repairing the perforation defect externally (23, 26, 28, 33). MTA (26, 28) and Biodentine (33) were used to obturate the external surface of resorption defect. In one treated tooth, surgical intervention was performed to remove granulations and excess CEM cement (23).

The perforation of the root was not detected in 13 teeth of IRR when conventional root canal treatment was applied (24, 26, 27, 29-32, 34, 35). The method of obturation for these roots varied among authors. HCS cements (MTA, Biodentin, Endosequendce BC RRM Fast set putty) were used in combination with gutta-percha to fill the root canal (30-32, 34). Some authors filled the entire root canal space using thermoplastic gutta-percha and sealer (24, 26, 30, 31), while others used cement (MTA, Biodentine) (27, 29, 35).

Outcomes of regenerative endodontic procedures in the treatment of internal root resorption

The follow-up period for all cases of IRR treated by REP ranged from 12 months to 6 years as it is shown in Table 4.

Clinical symptoms, changes in resorption

Table 5

Procedures for managing internal root resorption during root canal treatment and outcome

	Criteria / Article	Amount of treated teeth	clinical and radiological symptoms				root canal disinfection	intracanal medicament, exposure time, change frequency
			root perforation (bone destruction in resorption area)	pain/ percussion/ sinus tract	sensitivity test	periapical lesion		
1	Bendyk-Szeffer et al. (2015) (22)	1	Yes (P)	N/N	N	Yes	2% and 5,25% NaOCl, EDTA, saline	CaOH for 7 days
2	Ramazani M et al. (2016) (23)	1	Yes (P)	P/P/sinus tract	N	No	1% NaOCl	CaOH for 10 days
3	de Souza SN et al. (2017) (24)	1	No	P/P	P	No	2,5% NaOCl, 17% EDTA	One visit treatment
4	Subay et al. (2018) (25)	1	Yes (P)	P/NM/sinus tract	NM	No	saline, 5% NaOCl	3-month treatment with CaOH, it was renewed at various intervals
5	Mehra N. et al (2018) (26)	2	No	P/P	NM	Yes	2,5% NaOCl, saline, 10% citric acid	CaOH for 2 weeks
			Yes (P)	P/NM	NM	No	2,5% NaOCl, 10% citric acid	CaOH for 4 weeks
6	Patni PM. et al. (2018) (27)	1	No	N/NM	N	Yes	2,5% NaOCl, 17% EDTA, 2% CHX	CaOH for 2 weeks
7	Yildirim S. et al. (2019) (28)	1	Yes (P)	P/P	N	No	1% NaOCl, 17% EDTA	CaOH was changed once a month until the tooth was asymptomatic
8	Fráter M et al. (2020) (29)	1	No	N/NM	NM	Yes	5% NaOCl	One visit treatment
9	Tavsan O. et al. (2020) (30)	3	No	N/NM	P	No	2.5-3% NaOCl, 17% EDTA	CaOH for 1 week
				N/NM	P			
				P/NM	NM			
10	Pérez-Alfayate R. et al. (2020) (31)	3	No	P/P/sinus tract	N	Yes	5,25% NaOCl, 17%EDTA	One visit treatment
				P/P	N			CaOH for 2 weeks
				P/P	N			CaOH for 1 week
11	Mandviwala DK. et al. (2022) (32)	1	No	N/NM	NM	Yes	NM	CaOH for 2 weeks
12	Pawar S. et al. (2022) (33)	1	Yes (P)	P/P	NM	No	3% NaOCl	CaOH exposure time NM
13	Riyahi AM. (2022) (34)	1	No	P/P	N	No	5,25% NaOCl	One visit treatment
14	Gupta G. et al. (2022) (35)	1	No	N/N	N	Yes	2,5% and 5% NaOCl	1) CaOH for 2 weeks, 2) Triple antibiotic paste for next 2 weeks, 3) CaOH for next 2 weeks

P- positive; N -negative; NM- not mentioned; Pre-op- preoperative; Post-op- postoperative; CaOH- Calcium hydroxide paste; CHX - chlorhexidine solution; PA- periapical radiographs; CBCT- cone beam computed tomography.

Table 5

Procedures for managing internal root resorption during root canal treatment and outcome

	resorption site sealing material, root canal sealing material	additional surgical treatment (material used)	Follow-up time	Diagnostic assessment		outcomes	
				Pre-op	Post-op follow-up	destruction of periapical tissues	bone destruction in the resorption area
	MTA, warm GP, resin sealer	No	12 months	CBCT, PA	CBCT, PA	absent	absent
	CEM cement	Yes	12 months	CBCT, PA	NM	absent	absent
	thermoplastic GP, zinc oxide–eugenol sealer	No	12 months	PA	PA	absent	absent
	MTA	No	6 years	PA	PA	absent	absent
	thermoplasticized GP, resin sealer	No	18 months	CBCT, PA	PA	decreased	absent
	MTA, thermoplasticized GP	Yes (MTA)		CBCT, PA	PA	absent	decreased
	Biodentine	No	5 years	CBCT, PA	PA	absent	absent
	MTA	yes (MTA)	3 years and 6 months	CBCT, PA	PA	absent	decreased
	MTA	No	12 months	CBCT, PA	CBCT	decreased	absent
	GP, resin sealer	No	1 year	CBCT, PA	PA	absent	absent
	GP, resin sealer, MTA						
	MTA, GP	No	8 years	PA	PA	decreased	absent
			3 years				
	GP		8 years				
	GP, Biodentin	No	12 months	CBCT, PA	PA	decreased	absent
	GP, resin sealer	Yes (Biodentine)	12 months	CBCT, PA	PA	absent	absent
	GP, resin sealer, EndoSequence BC RRM-Fast Set Putty	No	18 months	PA	PA	absent	absent
	MTA	No	24 months	CBCT, PA	PA	absent	absent

defect and periapical tissue, as well as destruction of the bone in the resorption area, were evaluated.
After the follow-up period, all teeth, regardless of their symptoms prior to treatment (pain, tenderness to percussion, sinus tract) were asymptomatic.
According to the data provided by the authors, 5 teeth included (16-20) had perforating IRR, and 4 of 5 were diagnosed bone damage in the resorption area as well (17-20). Furthermore, the periapical lesion was evident in 2 of those cases showing combined pathology of alveolar bone in periapical and resorption areas (17, 20).
After evaluating the outcomes of the treatment, it was observed that the periapical lesions decreased in cases with a follow up period of 12 and 19 months (17, 21). In cases with a longer follow-up period of 3 years, there was no periapical lesion present (20). Similarly, cases that did not show any apparent damage of periapical tissues before the treatment, also had no periapical changes after the follow-up period (16, 18, 19) (Table 4).
Regardless the follow up period, the bone destruction in the resorption area decreased in cases of IRR with perforation (17-20). There were no new bone lesions observed over time in any of the treated teeth.
Changes in the IRR area was noticed after the follow-up period when REP was used for managing IRR. Radiographs showed evidence of calcification, mineralised tissue formation, incomplete hard tissue repair, or arrest of resorptive lesions, as reported in this review.
The treatment results of 4 teeth were evaluated using periapical radiographs (16, 17, 19), while the remaining 15 teeth were evaluated using CBCT (18, 20, 21).

Outcomes of internal root resorption treated by root canal treatment with/without additional surgical treatment
The follow-up period for all the cases of IRR managed by the entire root canal treatment, with or without additional surgical treatment, ranged from 12 months to 8 years (22-35). After the follow-up period, all the treated teeth were asymptomatic. When evaluating the periapical pathology of the teeth, it was found that 9 teeth had periapical lesions before treatment (22, 26, 27, 29, 31, 32, 35). Root perforation and bone destruction in area of IRR were identified in 6 teeth (22, 23, 25, 26, 28, 33). However, only one combined bone pathology was detected in cases treated by conventional root canal treatment, where lesions of the bone were evident in both areas (22). The bone destruction in the resorption and periapical areas was absent or decreased in all these cases, regardless of the follow-up period.
Healing results were evaluated using periapical radiographs (16 teeth) (24-28, 30-35) and CBCT (2 teeth) (22, 29). In one case (1 tooth), this was not mentioned (23).
All the authors reported that the resorption process in the root canal was arrested after root canal treatment regardless of the technique used for root canal obturation and surgical intervention for external repair of resorption defect when root perforation was present (23, 26, 28, 33).

Discussion

The management of internal root resorption (IRR) in endodontic practice presents a challenge due its complexity. The analysis of the included cases revealed various treatment options that need to be considered when diagnosing IRR along with other pathologies such as root perforation, periradicular lesions. While conventional root canal treatment remains the most common treatment approach, the regenerative endodontic procedure (REP) was introduced as an alternative aiming to stimulate reparative mechanisms and restore damaged tissue (36).
Symptomatology of IRR may vary depending on the clinical situation including tooth pain, a draining sinus tract, changes in tooth color, or even the absence of symptoms (7, 37). More than half of the analyzed cases reported discomfort associated with causative tooth or varying degrees of pain (17-21, 23-26, 28, 30, 31, 33, 34) although only 8 of them had a root perforation (17, 18, 20, 23, 25, 26, 28, 33). Interestingly, some cases showed no complaints or symptoms despite being diagnosed with root perforation (16, 19, 22). These findings suggest that the onset of

symptoms in case of IRR is not solely determined by root canal perforation.
It is evident that both the dental history and a thorough examination of the tooth are crucial for making an accurate diagnosis. The European Society of Endodontology (ESE) recommends using CBCT to precisely determinate the location and extent of the defect before deciding on a treatment plan (8). More than half of the authors in the studies included in this review used CBCT as diagnostic and treatment planning tool for cases of IRR (18-23, 26-30, 32, 33, 35). However, some authors relied solely on dental radiographs (16, 17, 24, 25, 31, 34), and only Subay *et al.* (24) mentioned that the patient declined to undergo a CBCT examination.
The varied clinical presentations observed in the analyzed cases of IRR, which include root perforation and bone destruction in the resorption site or(and) periapical lesions, create a complex scenario for treatment decision-making in order to achieve a successful outcome. Although root canal treatment has traditionally been the preferred approach for treating internal root resorption (38, 39, 40), the published clinical cases demonstrate that REP is also an option. The purpose of root canal treatment is to remove all pulp tissue, disrupt the activity of the damaging cells, and interrupt their blood supply, which is necessary for their nutrition. In order to achieve this goal, the root canal must be fully instrumented, disinfected, and filled along its entire length, including the area of resorption (41). The approach of REP aims to minimize the number of procedures and preserve as much of the root structure as possible. However, there is no established unique methodology regarding the application of REP for treatment of IRR, which remains a major issue for this treatment approach. Some authors (17,18, 21) who have treated IRR by REP have relied on the REP procedures typically used for cases with necrotic pulp in immature teeth as outlined in the guidelines of the American Association of Endodontists (AAE) or the European Society of Endodontology (ESE) position statement (42, 43). However, other authors (16, 19) have referred to these procedures as a novel treatment approach or MTA barrier placement for the treatment of IRR. Nevertheless, the common characteristic of all methodologies related to REP for the treatment of IRR is a focus on obturating the root coronally to the resorption using HCS, while leaving the apical part of the root and resorption area unfilled to promote hard tissue formation. The procedural differences include the area of the root that is instrumented (only the coronal part until the resorption area or the entire root canal), the type of medication used for disinfection of the root canal/resorption area and the duration of intracanal dressing with temporary disinfection material (Table 4). Some authors have chosen to remove the necrotic pulp tissue from the coronal part of the root, leaving the tissues apically over the resorption area without any mechanical shaping procedures (16, 19, 20), while others have instrumented the root canals through full working length (17, 18, 21). In clinical study (21), where 13 teeth were treated by REP with injectable PRF, according to the author, pulp status was necrotic in 10 teeth and vital in 3 teeth, although there was no mention about performing a sensitivity test before treatment. Later, during and after the treatment, a sensitivity test was performed on all 13 teeth to check sensitivity regain, but it revealed negative throughout the observation period. Despite REP procedure implies the regeneration of the pulp tissues so consequently expects the positive pulp sensitivity tests, it should be noted that negative pulp sensitivity test reaction could not be treated as a procedure failure as well as pulp sensitivity test result is not equivalent to real pulp vitality status (44).
Although the treatment strategies of root canal treatment and REP differ, the use of common medicaments such as NaOCl and $Ca(OH)_2$ in protocols of both methods emphasizes their essential roles in disinfection and tissue repair. In almost all analyzed cases root canals were irrigated with 1-5,25% NaOCl (16-31, 33-35). Additionally, saline or distilled water (16-18, 21, 22, 26), 17% EDTA (17-22, 24, 27, 28, 30, 31),

chlorhexidine solution (16, 27) and 10% citric acid (26) were used in most cases. Only 5 out of 38 analyzed cases underwent one-visit treatment (1 for management of IRR by REP (19), 4 for management of IRR by root canal treatment (24, 29, 31, 34)). In other 33 treated teeth, the authors indicate that $Ca(OH)_2$ was used as an intracanal medicament between visits (16-18, 20-23, 25-28, 30-33, 35). Calcium hydroxide can be used not only because of its antimicrobial and disinfection properties (45), but also it can be used during REP procedures as it is evident, that the hydroxide ions released from $Ca(OH)_2$ cause sterile necrosis in remaining untouched pulp tissues (46). This pulp necrosis promotes healing and repair of the pulp tissue by encouraging irritation. As a result, odontoblasts actively produce collagen, and the presence of calcium ions contributes to its mineralization (47). This process is suggested to cause the recovery of damaged tissue. The period of intracanal dressing with $Ca(OH)_2$ varied between 2 weeks and 4 years in cases treated by REP (16-21) and from 1 week to 3 months in cases treated by root canal treatment (22-35). An exceptionally long-term treatment period (2-4 years) with $Ca(OH)_2$ was carried out by Ebeleseder and Kqiku (16) in cases of management of IRR by REP. Some authors (17, 35) used triple antibiotic paste for two weeks in addition to the initial use of $Ca(OH)_2$ for intracanal dressing.

Regardless of the duration of intracanal application of $Ca(OH)_2$ the radiographs of all clinical cases treated with REP showed the presence of calcification, mineralised tissue formation, incomplete hard tissue repair, or arrest of resorptive lesion. Some studies have highlighted the negative effect of long-term $Ca(OH)_2$ treatment on dentin microhardness and fracture resistance (48-50). Therefore, the long term use of $Ca(OH)_2$ as an intracanal dressing could be controversial. It could be speculated that radiological outcomes of IRR treatment with REP may depend on the follow-up period, as different outcomes such as reduction in size of the resorption defect or formation of hard tissue in the resorption area have been observed at follow-ups of 12-19 months (17, 21) and 2-6 years (16, 18-20), respectively (Table 4).

The HCS cement was used alone or in combination with gutta-percha and sealer for the obturation of root canals in analyzed cases of IRR that were treated by REP or root canal treatment. MTA was the preferred cement in all cases treated by REP followed by Biodentin, Endosequence BC RRM Fast set putty, CEM which were chosen by some authors to treat IRR by traditional root canal treatment. When REP was applied, the tissues of resorption area, as well as the tissues remaining apically from the resorption, were isolated by obturating the coronal part of the root with MTA in all cases analyzed (16-20). The exception regarding the REP technique, compared with other case reports included in this review, was described by Negeh M. *et al.* (21). After chemo-mechanical preparation of the root canals and intracanal medication with $Ca(OH)_2$ for 2-4 weeks, the authors filled the orifices of the root canals (3mm thick layer) with white MTA directly over the platelet-rich fibrin, regardless of the location of resorption area in the root canal. According to the results of their study, the resorption area reduced in size in all the cases included after a 12 months follow-up.

Although there are no uniform methodologies and protocols for treatment of IRR by REP, the outcomes of published cases are similar. The clinical symptoms, such as pain, discomfort related to the causative tooth or sinus tract, disappeared and did not recur. The resorption area either reduced in size or was repaired by hard (mineralized) tissue formation as mentioned above. Additionally, bone destruction regardless of its location (in periapical or resorption area), either was absent or reduced in size during radiological evaluation of treatment outcomes. Two of the analyzed cases treated by REP (17, 20) and one treated (22) by root canal treatment, presented combined pathology, including perforating IRR and apical periodontitis. The radiological assessment of the pathology and treatment outcomes, conducted by periapical radiographs (17) or CBCT imaging

(20, 22), showed healing of periapical tissues and bone repair in the resorption area in all three cases mentioned above. Managing IRR with root perforation by root canal treatment, additional surgical procedures were applied, including the removal of granulation tissues from the bone in resorption area and obturation of the defect on the external surface of the root using HCS cement (23, 26, 28, 33). Nevertheless, some of the cases with perforating IRR were treated without surgical intervention showing favorable outcomes as well (22, 25). Thus, it could be supposed that the need of additional surgical procedures when treating IRR with perforation by root canal treatment depends on the clinical symptoms and the size of the defect.

According to the analyzed cases, it could be suggested that the main advantage of REP over root canal treatment is the potential for damaged tissues to recover on the resorption site, which allows for tooth strength by preserving more of the root structure for healing. Technically, both procedures can be challenging for clinicians. However, using REP to manage IRR, there is no need to clean the resorption area. Considering that root canal treatment is already difficult procedure to perform, it can be speculated that REP is a less difficult treatment method and a more conservative approach for clinicians compared to root canal treatment.

The findings of this review highlight the importance of individualized treatment strategies that are tailored to the specific clinical presentation of IRR. This emphasizes the need for a holistic approach that takes into account patient's dental history, a thorough clinical examination, and an understanding of the mechanisms behind IRR pathogenesis.

A limited number of reported cases, as well as only one clinical study found in the scientific literature, may be considered as limitation of this review. The certainty of evidence derived from case reports is debated and generally considered low (51). Additionally, the exact prevalence of IRR is poorly documented in the literature (52). Moreover, the pathology of root resorption is rarely encountered in clinical practice, making it difficult to obtain a sufficient sample size for clinical studies and higher levels of evidence.

Therefore, it could be speculated that relying on published clinical cases for decision-making would be reasonable, when other higher levels of evidence are not available. The need for further clinical research to comprehensively evaluate the long-term effects and comparative efficacy of identified treatment options for managing IRR remains evident.

Conclusion

Both root canal treatment and regenerative endodontic procedures (REP) provide comparable and favorable outcomes for managing inflammatory internal root resorption (IRR). REP may offer advantages, such as preserving more root structure and enhancing tooth strength, as it avoids cleaning the resorption area. Ultimately, the choice between these methods should be based on a careful assessment of the clinical situation and the patient's dental history.

Clinical Relevance

The review emphasizes the importance of individualized treatment strategies and highlights the potential of REP to preserve more root structure and enhance tooth strength in the cases of IRR.

Conflict of Interests

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CASE REPORT

Late re-implantation (48 hours) of an avulsed upper central incisor to preserve function, esthetics and alveolar bone for eleven years

ABSTRACT

Aim: *To describe the clinical management of a tooth re-implanted late to maintain functionality, esthetics and alveolar bone preservation.*

Summary: *A healthy 11-year-old female patient presented 48 hours after avulsion of the left upper central incisor, which was carried in a paper napkin. The tooth was rinsed with physiological solution, conditioned with sodium fluoride and root canal treatment was performed extra-orally. The tooth was immersed in distilled water mixed with MTA, the blood clot was removed from the socket and the tooth was re-implanted and splinted. The patient had a prescription for antibiotics, analgesics and a tetanus vaccination. After 8 days, the patient was asymptomatic with no mobility and mild gingival inflammation. The splint was removed 2 months later. At 8 months, resorption by substitution began and was followed for 1 to 7 years, at which time resorption by substitution occupied approximately 95% of the root, but without mobility. After 11 years of re-implantation, the remains of the crown and the gutta-percha were removed from the alveolus. The re-implanted tooth served to preserve the bone without the need for bone grafting, as alveolar bone was formed as the tooth resorbed.*

Key Learning points:

- *The avulsed and re-implanted tooth, even late, maintains masticatory function and prevents psychological distress for the patient.*
- *Late re-implantation of the avulsed tooth allows alveolar preservation with functional bone and provides better support for the placement of an osseointegrated implant.*

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Introduction

The oral region represents 1% of a person's body surface area, but receives 5% of all physical injuries (1-3), with a high incidence of anterior dental trauma in people aged 7-12 years (4-6), with a prevalence in the permanent dentition that varies from 0.5% to 16.0% (7,8). In addition, the loss of an anterior tooth at a young age, can lead to bullying, embarrassment when laughing, exclusion from peers at school (9,10) which can cause shyness in some people, affecting their self-esteem and even their social interaction and economy (11).
The World Health Organization classification of trauma (7) divides them into injuries that affect hard tissues, such as teeth, periodontium, bone or a combination of these anatomical structures (1). These injuries require specific and immediate treatment (1). One of the most serious traumas is tooth avulsion, which is the complete displacement of a tooth from its original position in the mouth. This trauma is of such magnitude that it causes rupture of both the periodontal ligament and the pulp tissue (12). Reimplantation is the ideal treatment for the avulsed tooth, defined as the return of the tooth to its socket (13), preferably as soon as possible and especially in patients in the dental development phase (14).
Avulsion results in pulp necrosis due to pulp rupture and damage to periodontal ligament cells. Damage to the periodontal ligament is related to the extra-oral time and extra-oral storage conditions of the avulsed tooth. The most recommended liquids to keep teeth out of the socket are Hank's balanced solution or milk (12); more recently, storage and transport boxes have been suggested (1). The advantage of milk is that it is easy to obtain, unlike transport boxes or Hank's solution. Other factors that influence the prognosis of the pulp tissue and periodontal ligament are apical foramen diameter, root canal length and proper handling (15).
Unfortunately, in some cases reimplantation is not performed immediately and the tooth is stored in an inadequate medium or in a dry medium prior to reimplantation (12). These situations result in the absence of viable cells in the periodontal ligament attached to the root surface (7). The lack of viable cells and the denatured collagen in the root surface promote an inflammatory process upon reimplantation, followed by alveolar remodelling, in which clastic cells are formed and deposited on the root surface, initiating superficial root resorption (12,16), which may progress to resorption by substitution or ankylosis (12).
There is a low level of knowledge in the population and in the educational sector about the best actions to take after dental trauma (17,18), which may be due to inadequate attention in medical institutions (2) or to the knowledge barrier between dentists, physicians, teachers, coaches, etc. (3). This is observed because the avulsed teeth arrive at hospital centers or dental offices in dry storage or reimplantation is not considered. A person who has had an accident should be treated with first aid to save his life, but the initial treatment of an avulsion is not so complex, it only consists of reimplanting the avulsed tooth at the site of the accident (1).
Another important aspect of the loss of a front tooth in young patients who are still growing and developing, is that the avulsed tooth cannot be replaced by an implant, as this would give an unaesthetic result as the person's jaw grows. If the avulsed tooth is not repositioned, the alveolar ridge will collapse due to the lack of masticatory stimulus and when the patient is an adult, he/she will require bone grafting to achieve a stable alveolar process for an implant (1).
The purpose of this clinical case is to describe the clinical management of an avulsed tooth that was reimplanted 48 hours after avulsion to preserve tooth function and preserve the alveolar process, for placement of an osseointegrated implant in adult stage.

Case report

An 11-year-old female patient presented to the dental service of the Regional Military Hospital of Guadalajara, Mexico, with an

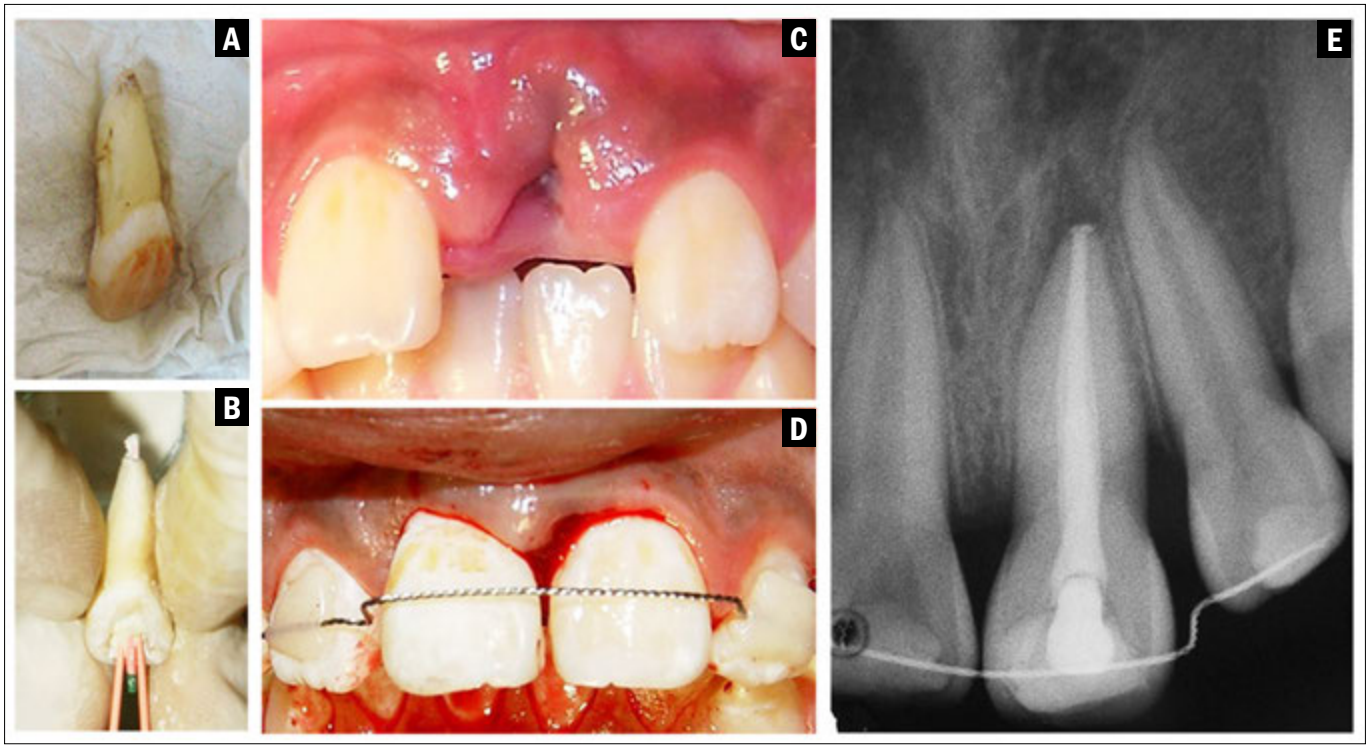

Figure 1
A) Avulsed tooth #21 transported in a paper napkin; **B)** extraoral root canal treatment; **C)** partial collapse of the socket after avulsion; **D)** replantation of tooth #21; **E)** radiographic aspect of the replanted tooth.

avulsion of the left upper central incisor (tooth #21) caused by a fall from a mechanical toy. The tooth was found at the scene of the accident after 24 hours; the parents kept the tooth in a dry paper napkin for a further 24 hours and it was then taken to the Endodontic Clinic (Figure 1A).

Clinical examination revealed a collapsed alveolar space (Figure 1B), healing, minimal swelling and mild pain. A conversation was held with the parents about the therapeutic options and their future prospects, which were to wait for the alveolar space to heal and to fabricate a temporary prosthesis. This option has the disadvantages of chewing, aesthetic and psychological impairment and in the absence of chewing stimulus for the development of the premaxilla, the alveolar process would collapse and bone grafting may be necessary in the future if an implant is considered in this area.

The other therapeutic option proposed was to re-implant the tooth, informing the patient and her parents that the tooth would be resorbed by root replacement due to the extraoral dry period. The advantage of this procedure is that the patient would regain masticatory stimulus in the region and the bone would maintain the normal thickness of the alveolar process by replacing the root, making it more receptive to a future implant. Aesthetically, the patient would retain her own natural appearance. It was explained to them that, with appropriate treatment, the tooth could remain in the mouth for several years, but that the prognosis was that sooner or later it would be resorbed. Both the patient and her parents decided to have the tooth re-implanted.

The tooth was examined and found to be free of fractures, fissures or debris; it was washed with 0.9% sodium chloride solution (Lab. Pisa, Guadalajara, México). The tooth was placed in 2.5% sodium hypochlorite solution for three minutes to remove necrotic tissue from the periodontal ligament and to disinfect it. It was conditioned with 2% sodium fluoride (Fluordent, Lab. Altamirano, México City, México) for 20 minutes.

Root canal treatment was performed extraorally (Figure 1C). Palatal access to the root canal was obtained using a #2 tungsten carbide bur at high speed and water spray irrigation. The cervical and middle thirds were enlarged with Gates-Glidden 2-4 drills (Maillefer/Dentsply, Ballaigues, Switzer-

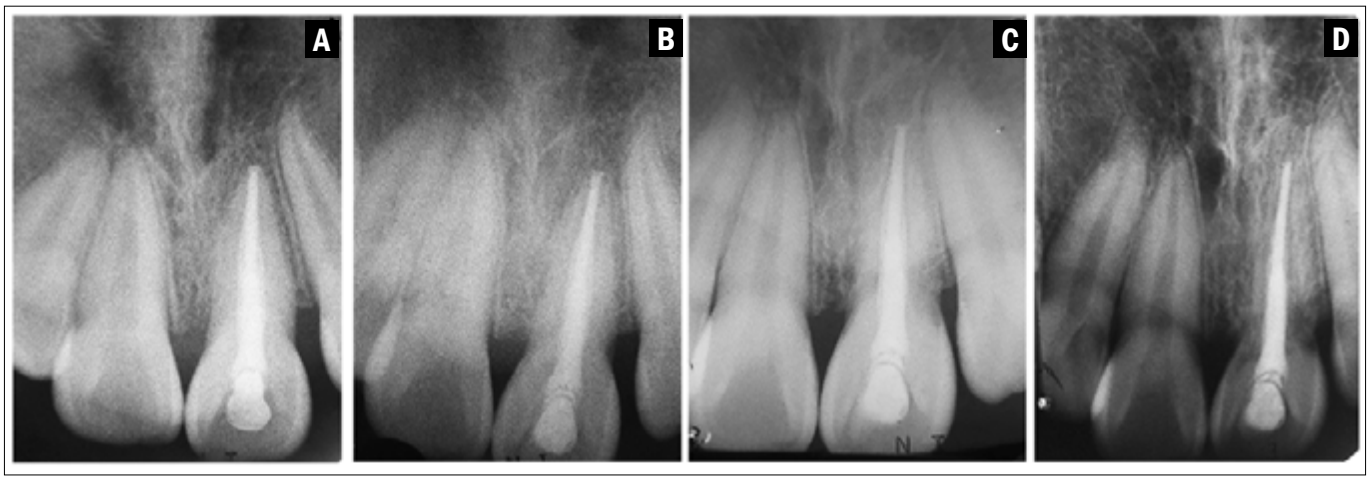

Figure 2
Radiographic controls of reimplanted tooth #21. **A)** 6 months - adequate evolution; **B)** 1 year - minimal areas of resorption; **C)** 2 years - larger areas of resorption; **D)** 3 years - resorption of approximately 50% of the root surface.

land) under copious irrigation with 2.5% NaOCl (Clorox, CDMX, Mexico). The root canal length was obtained by subtracting 1 mm from the length of a #20 K-file when its tip was visualised in the foramen. Chemomechanical preparation was performed with K files (Maillefer/Dentsply) up to file 50, irrigated with 2.5% sodium hypochlorite. The canal was dried with sterile coarse paper tips (Kerr, Glendora, USA). White MTA cement (Angelus, Londrina, Brazil) was prepared and delivered to the canal with a #40 Lentulo spiral 40 and gutta-percha cones (Hygenic, Akron, USA) were placed. Excess cones and cement were hot trimmed and the pulp chamber was irrigated with water. The coronal access was sealed with light-curing composite (3M Filtek, 3M Espe, St Paul, USA).

To alkalinise the root surface, the tooth was placed in a solution of distilled water mixed with MTA (Angelus) for 20 minutes while the alveolus to receive the reimplanted tooth was prepared. The patient was regionally anaesthetised with 3% mepivacaine without vasoconstrictor (Septodont, Saint-Maur-des-Fossés, France) and the clot present in the socket was gently removed with a curette (Septodont, Saint-Maur-des-Fossés, France) and the clot present in the alveolus was gently removed with a Lucas curette and rinsed with 0.9% saline solution, without carving the walls of the alveolus. The tooth was gently reimplanted in its own socket, its proper occlusion was verified and it was fixed with a semi-rigid splint made of 0.18 twisted orthodontic wire ligature (Dentaurum, Ispringen, Germany) from the right maxillary lateral incisor (tooth #12) to the left maxillary lateral incisor (tooth #22) with light-curing resin buttons (3M Filtek). Gentle digital compression was applied to the gingival tissues with moist sterile gauze for three minutes, to bring them as close to the root surface as possible (Figure1D). An analogue periapical radiograph (Kodak, Guadalajara, Mexico) was taken to verify adequate root position (Figure 1E). Amoxicillin 250 mg every 8 hours for 7 days and acetaminophen 150 mg every 8 hours for 5 days were prescribed, along with tetanus vaccination. After 8 days, the patient was asymptomatic, no mobility of tooth #21, and good stability of the splint; the gingival tissue showed mild inflammation.

After 2 months, tooth #21 had no mobility and the splint was removed. The gingival tissues were with no inflammation; radiographically there was no evidence of resorption or apical pathology, but slight widening of the periodontal ligament. At the 6-month control, radiographic absence of periodontal ligament space in the mesial root wall was observed, but no evidence of resorption (Figure 2A). Clinically, the gingival tissues were healthy and the tooth was immobile. At 8 months, radiographic resorption by substitution was observed in the distal wall of the middle third of the root, absence of periodontal space in the mesial wall, periapical area without radiolucent zone, as well as the beginning of resorption of the root apex.

At the clinical-radiographic control 1 year after reimplantation, the patient was as-

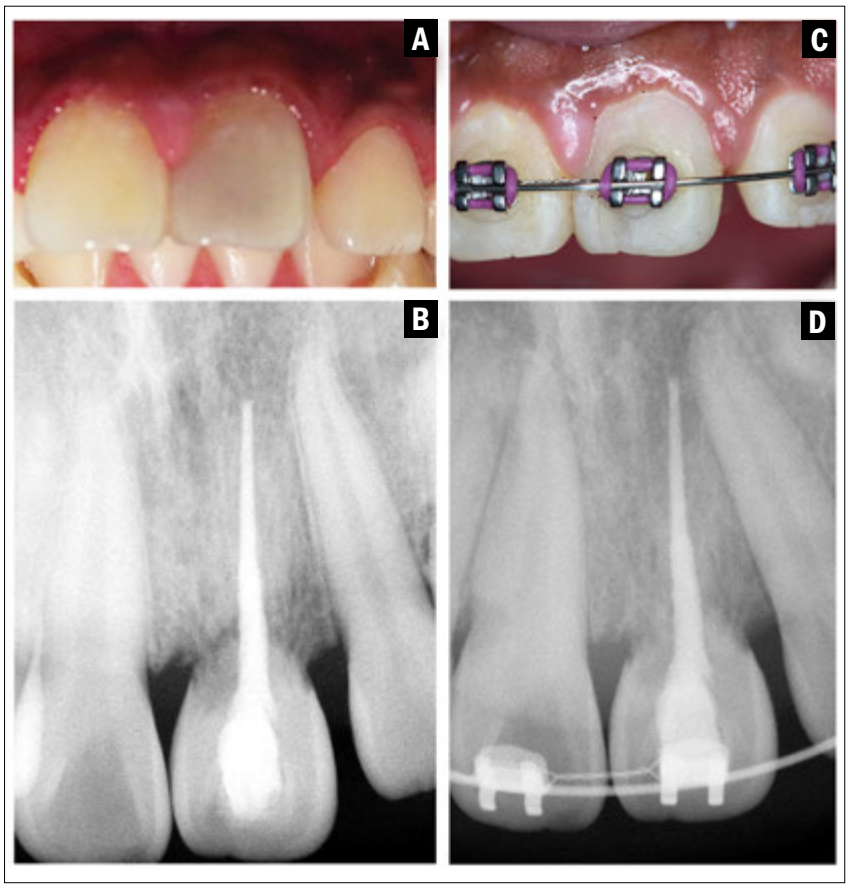

Figure 3
Clinical radiographic controls of tooth #21 after reimplantation. **A)** moderate darkening of tooth #21 (4 years); **B)** replacement resorption of more than 50% of the root surface (4 years); **C)** inflammation of the marginal gingiva of tooth #21 (5 years); **D)** replacement resorption of about 75% of the root surface (5 years).

ymptomatic, with no tooth mobility and adequate gingival tissue attachment. It was decided to change the composite because of the colour change caused by filtration. Radiographs showed loss of periodontal ligament space throughout the root, minimal areas of root resorption in the middle and apical third, absence of radiolucent zone, and loss of apical tooth structure (Figure 2B).

Two years after reimplantation, the patient remains asymptomatic in her clinical-radiographic control, with good tissue attachment, absence of inflammation, no sinus tract, and minimal inflammation of the marginal gingiva. Radiographically, there were more areas of apical root resorption, no visualisation of the radicular periodontal ligament space, and small radiolucent areas at the cervical level in the distal wall of tooth #21 (Figure 2C).

At the 3-year clinical and radiographic follow-up, the patient was asymptomatic with adequate gingival attachment, lack of mobility, and inflammation in the marginal gingiva of tooth #21. Radiographically, resorption by replacement of approximately 50% of the radicular surface was observed, with the presence of a radiolucent area in the distal and mesial wall at the level of the amelocemental junction (Figure 2D).

Four years after reimplantation, the patient was still asymptomatic, clinically there was a change in crown colour due to composite filtration and slight inflammation at the marginal gingival level in both incisors (Figure 3A). Radiographically, there was resorption due to replacement of more than 50% of the root surface, but areas of the root were still visible. Bone ingrowth was observed in the crown, as well as minimal radiolucent areas. (Figure 3B).

Four and a half years after the reimplantation, the patient began orthodontic treatment. Five years after the reimplantation, at the clinical-radiographic control and 6 months after the start of orthodontic treatment, there was inflammation of the marginal gingiva in both incisors, with no change in colour, no mobility, no pain and no sinuous tract (Figure 3C). The radiograph showed resorption by substitution in more than 80% of the root surface, as well as free gutta-percha in the alveolar space (without radiolucent areas), and small radiolucent areas in the clinical crown, however, but with the appearance of bone invagination in tooth #21 (Figure 3D).

6 years later, the patient was asymptomatic, without mobility, and continued with orthodontic treatment (minor movements). Dyschromia of the clinical crown of tooth #21, mild inflammation and minimal gingival invagination on the vestibular surface of tooth #21 was observed (Figure 4A). Radiographs showed resorption of approximately 90% of the root surface, no alveolar bone loss and minimal radiolucent areas in the clinical crown (Figure 4B).

Seven years after the reimplantation, the patient remained asymptomatic and compliant with her orthodontic treatment. Gingival inflammation and invagination in the marginal zone of tooth #21, dyschromia, and grade 1 mobility were observed (Figure 4C). The radiograph showed replacement resorption of approximately 95%

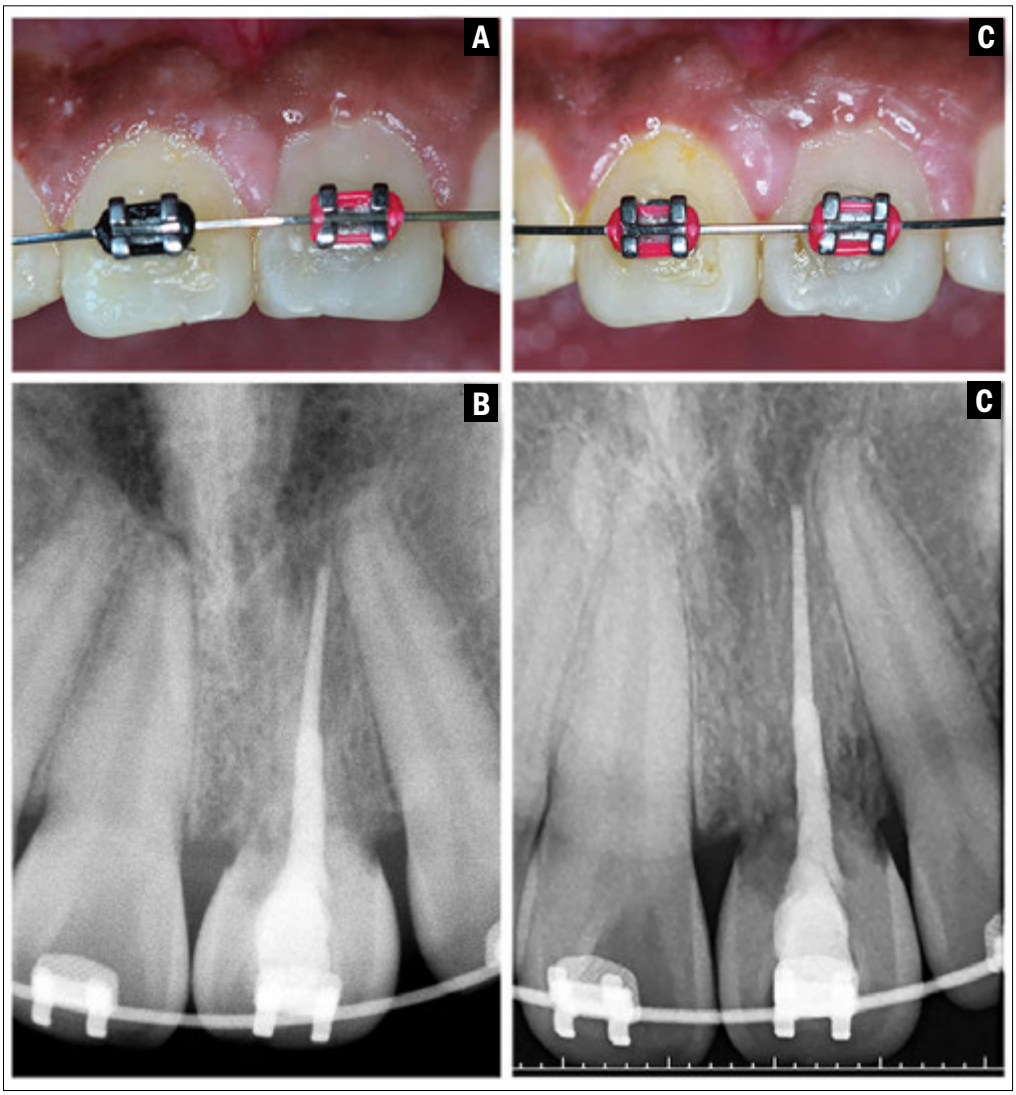

Figure 4
A) Moderate darkening of tooth #21 and marginal gingival inflammation (6-year control); **B)** replacement resorption of approximately 85% of the root surface (6 years); **C)** crown discolouration and increased marginal gingival inflammation (7 years); **D)** replacement resorption of approximately 95% of the root surface (7 years).

of the root surface, with bone ingrowth in the crown and radiolucent areas in the mesial and distal walls, suggesting intense osteoclastic activity on the reimplanted tooth (Figure 4D). At this appointment, it was recommended that the tooth be extracted and an implant placed. However, the patient did not accept this and preferred to keep the tooth.

The patient returned **11 years after reimplantation** with exaggerated mobility of tooth #21. On examination, the clinical crown was pinkish with gingival invagination on the vestibular surface and inflammation in both central incisors, more pronounced in tooth #21. The patient was without brackets as she had discontinued orthodontic treatment. Tooth #21 was in infraocclusion. It was painless but with intrusive mobility (Figure 5A); radiographically, no root structure is observed, as well as separation of the crown from the bone and minimal union with the gutta-percha, good level of the alveolar bone, absence of radiolucent areas and no adjacent pathology (Figure 5B). A CBCT was obtained and the sagittal and axial slices showed adequate bone formation with sufficient thickness for implant placement (Figures 5C and 5D). It was explained to the patient that it would be necessary to remove the coronary portion, the remaining gutta-percha and place an osseointegrated implant (Hiossen, Englewood Cliffs, USA) with an acrylic temporary (Figures 5C-5F). The patient consented and the procedure was completed.

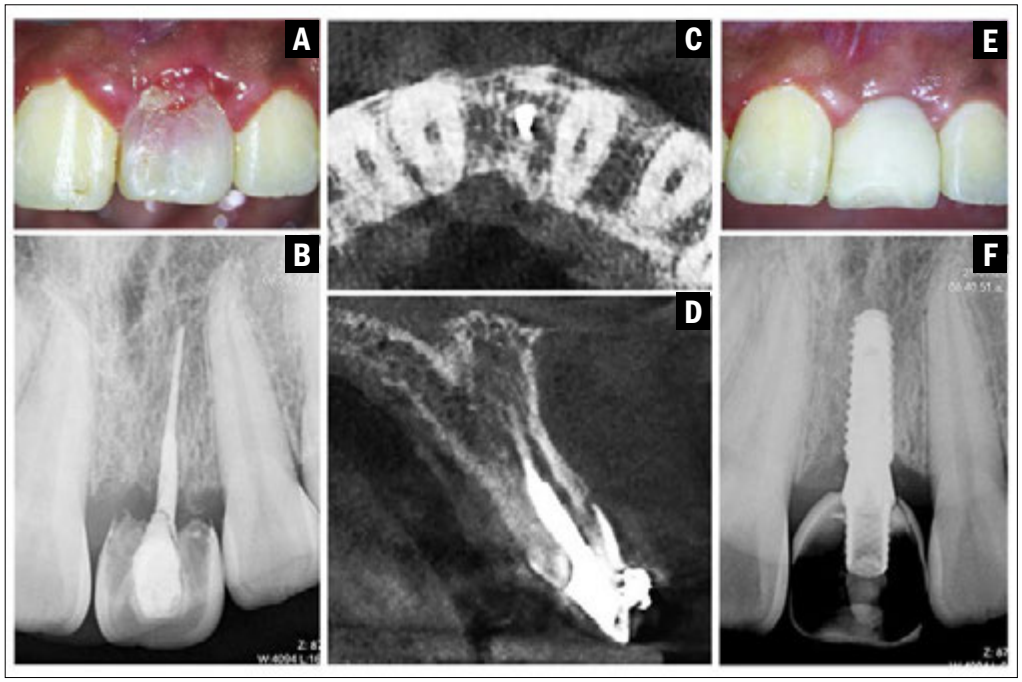

Figure 5
Control at 11 years. **A)** Pink staining of the clinical crown of tooth #21 and inflammation with bleeding of the marginal gingiva; **B)** total resorption of the root; gutta-percha can be seen in the alveolar bone; **C)** axial CBCT section showing how the bone has replaced the root; **D)** sagittal CBCT section showing preservation of the vestibular and palatal alveolar bone; **E)** clinical aspect of the acrylic temporary on the implant (6 months); **F)** radiographic aspect of the osseointegrated implant in the space of tooth #21.

Discussion

According to the guidelines of the International Association of Dental Traumatology (IADT), avulsed teeth should preferably be reimplanted at the site of the accident (19, 20), and if this is not possible, it is recommended that they be taken immediately to the dentist and transported in saline solution. Other solutions such as Hank's solution (21), Viaspan, Dentosafe, contact lens solution, milk, Gatorade, saliva or drinking water can also be used (22, 23). In this case, the avulsed tooth had been dry for 48 hours prior to treatment, so it is assumed that necrosis of the periodontal ligament cells had occurred. For this reason, it was decided to perform the extraoral root canal treatment in the same session prior to reimplantation, taking into account the IADT protocol for post-trauma reimplantation (19, 20), which states that if the teeth are dry outside the socket for more than 60 minutes, the root canal treatment can be performed extraorally prior to reimplantation, since there is no possibility of revascularisation of the pulp tissue and the periodontal ligament is necrotic.
Despite the prognosis of root resorption, it was decided to reimplant the tooth, mainly because she was a young patient and because she met the three requirements of late reimplantation after trauma, which are to preserve the aesthetic, functional and psychological aspects of the patient (19), since the loss of the tooth could provoke bullying and unpleasant situations in her social environment. Similarly, due to her age, the purpose of reimplantation was to preserve the natural soft tissues, to allow bone formation as the tooth resorbed and to preserve the alveolus for an implant when the patient reached adulthood.
When a tooth is reimplanted late, it is clear that inflammatory resorption and ankylosis, characterised by fusion of the alveolar bone and cementum, will occur. Soares et al (2015) (24), in a retrospective study, found that replacement resorption was present in 87.2% of cases following late reimplantation. This is due to the absence of a viable periodontal ligament (25, 26). To prevent or delay the process of ankylosis and inhibit root resorption (27, 28), three aspects should be considered: first, root surface treatment, second, root canal treatment, and third, antibiotic therapy (29). Regarding the use of medication, tetracycline is considered the indicated antibiotic as it reaches adequate levels in the gingival crevicular fluid and can help to control resorption (27, 28), however, it could in-

crease tooth colour change in patients aged 12 years or younger (30), and as the patient was 11 years old, amoxicillin was preferred as the antibiotic of choice.
It has been reported that one of the main factors in external root resorption is the presence of necrotic remnants of the periodontal ligament (29), but this is a controversial aspect as different techniques and procedures have been recommended to clean the root surface, such as periodontal curettes, scalpel blades, diamond burs, sodium hypochlorite and even pumice stone to clean the root surface (31). In the present case, the tooth was first immersed in NaOCl and then in 2% sodium fluoride for 20 minutes to avoid mechanical damage to the root cementum by the instruments. Sauro et al (32) showed that dental hard tissues, when immersed in 5 to 10% sodium fluoride solutions, have the ability to become fluoride-containing biocrystals similar to hydroxyapatite.
Other studies have suggested sodium fluoride, stannous fluoride, tetracycline, citric acid, hypochlorous acid, calcium hydroxide, formalin, alcohol, bisphosphonates and even indomethacin to prevent root resorption (7). Fluoride is thought to act on the cement, converting hydroxyapatite to fluorapatite (32), which is harder, inhibits bacterial growth, and may delay osteoclast metabolism and activity (29).
However, there is no consensus on the fluoride, concentration and timing of application in late reimplantation. Zuhal (31) reported that a reimplanted tooth remained in the mouth for 16 years without external root resorption. They used a topical gel of 1.23% acid fluoride phosphate for 15 minutes followed by rinsing with saline. The tooth was kept in distilled water mixed with MTA cement and obturated in the same session with gutta-percha+MTA cement to alkalinise the external and internal root surfaces prior to reimplantation (33). Krug et al (35) describe the survival of an upper central incisor reimplanted for 18.5 years, in which the tooth was kept dry for 1 hour and in physiological solution for 3 hours. Prior to reimplantation, the tooth was immersed in 2% sodium fluoride for 20 minutes; root canal treatment was started at 14 days, medicated with calcium hydroxide and obturated at 3 months. Two years after reimplantation, resorption and ankylosis were observed clinically and radiographically, which progressed slowly, allowing functional retention of the teeth with favourable esthetics. Savas et al (25) treated two patients aged 8 and 10 years with avulsion of the maxillary central incisors; the teeth were outside the alveolus for 27 and 7 hours respectively, so endodontic treatment was performed extraorally, followed by reimplantation.
Clinical radiographic controls were performed at 18 months for the 8-year-old patient and at 12 months for the 10-year-old patient. During these control periods the teeth were stable, but with resorption by substitution and ankylosis. They consider that despite the long time out of the socket in an unsuitable (dry) environment, the teeth should be reimplanted, especially in patients in the growth and development phase.
Tattullo et al (34) state that the recruitment of bone stem cells and bone growth molecular factors to the area provides a means for tissue remodelling. It is possible that this management during tooth reimplantation may have favoured the 11-year permanence and alveolar bone preservation in the present case. The tooth was used to maintain the surrounding bone for the years required for the patient to receive an implant.
The long-term prognosis of late reimplanted teeth is poor and their survival uncertain, despite IDT guidelines on reimplantation. Currently there is no clear guidance on the treatment protocol for severe external root resorption due to a lack of clinical and scientific evidence. Sometimes it is based on personal judgments, as most of the available treatment options are in case series or individual reports. Therefore, the treatment plan should be based on clinical judgment of each individual case. The opinion of orthodontic, prosthodontic and endodontic specialists is usually required (37).
The progression of external resorption

depends on the conditions of each patient, including age and systemic factors that regulate bone remodelling. In adult patients their bone remodelling is slower, whereas younger people have a rapid bone metabolism. This means that the prognosis of a late reimplanted tooth is better in adult patients than in young patients (35).
The clinical advantage of reimplantation, even at a late stage, is that the alveolar ridge bone is preserved, allowing subsequent implant placement without the need for bone grafting, as in this case. In addition to the age of the patient, the immune response should be considered, which plays an important role in the outcome of reimplanted teeth after avulsion (36). Atopic patients have less tooth loss, whereas non-atopic patients have more root resorption during the first 5 years after trauma, although in this case the atopic or non-atopic status of the patient was not considered (38).
Regarding the long-term survival of reimplanted teeth, Sangiovanni et al. (39) carried out a systematic review of the literature and found a success rate of 87.2% of reimplanted teeth, confirmed a high degree of reproducibility of the treatment, and considered that the success of the treatment is favoured by the reduced extra-alveolar storage time of the reimplanted tooth.
They consider it to be a viable therapeutic option, with an adequate success rate and high predictability. The overall survival expectancy of a late replanted tooth is 50% after 5.5 years (7), similar to the 4.7 years reported by Pohl et al (40). However, Petrovic et al (41) reported it to be 2.5 to 5.5 years in immature teeth, but Wang et al (42) reported that it can last up to 11 years in fully developed roots, as reported in this case.
However, the present case was out of the mouth for 48 hours and yet the tooth was retained for 11 years before extraction and placement of an implant, although the tooth had already been resorbed for 7 years and had no mobility, the patient decided to wait until she had severe mobility, knowing that her tooth would have to be extracted.

Conclusion

Late reimplantation of the avulsed tooth allowed the tooth to remain functional for 11 years and provided a positive psychological impact to the patient while the tooth was in the mouth, in addition to preserving the alveolar bone for placement of an osseointegrated implant.

Clinical Relevance

Re-implantation of an avulsed tooth after a long period of dryness allows the child or adolescent to maintain their chewing physiology and grow without psychological problems, and although the tooth is resorbed after a while, the root space is occupied by physiological bone, allowing the placement of an implant in better biological conditions.

Conflict of Interest

None.

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CASE REPORT

Successful treatment of a damaged upper molar using 3D Technology: a case report with 4 years follow-up

ABSTRACT

Aim: *To describe, in a stepwise manner, the diagnosis, treatment planning, execution, and rehabilitation of damaged upper molar using Sicat Endo software and a computer-aided design/computer-aided manufacturing (CAD/CAM) system.*

Summary: *A patient with no painful symptoms presented to our clinic to complete a treatment that had been initiated a year ago (left unfinished for personal reasons) to save the tooth. Clinical tests indicated a previously initiated therapy and normal apical tissues. Cone beam computed tomography (CBCT) was used for the diagnosis and treatment planning of the root canal procedure. The planning of the previously designed access cavity and identification of all the root canals was performed with Sicat Endo software (Sicat, Bonn, Germany). Additionally, the quality of the final root canal obturation was evaluated using Sicat Endo software. The final crown restoration was fabricated using a CAD/CAM system and pressed lithium disilicate material. The present case report revealed a successful four-year follow-up of a one-session endodontic treatment of a maxillary molar and CAD/CAM final restoration using digital technologies and 3D software.*

Key learning points

- *In the present case report, Sicat Endo Software was used for root canal treatment planning and for assessing the quality of final obturation.*
- *The present case report utilized CAD/CAM technology for one-session treatment.*
- *This case report presents a middle-term follow-up of four years on the use of digital technologies for one-session endodontic therapy and prosthetic rehabilitation.*

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Introduction

Endodontic treatment has been demonstrated to be a predictable procedure, with effective canal disinfection and root canal obturation (1). Guillen et al. in a systematic review and meta-analysis revealed that all aspects of restoration impact the overall outcome (2). A satisfactory coronal restoration significantly improves the result of root canal treatment, using "healthy periapical tissues" as a measure for success (3). A clinical prognosis study showed that if the final restoration was completed in less than a week, the success rate was 82.4%, compared to cases where the restoration was placed after more than a week, which had a success rate of 49.1% (4). A significant association between the type of restoration and "tooth survival" has been documented (5). Higher survival rates for teeth restored with indirect restorations compared to those restored with direct restorations have been reported (6). Endodontic procedures can be made more comfortable and efficient with the use of digital imaging, 3D software planning, and advanced instrumentation. Cone beam computed tomography (CBCT) imaging is an indispensable tool in the diagnosis and treatment planning of root canal treatment due to its enhanced capacity to reveal the detailed morphology of the endodontic system and to locate calcified root canals (7).

3D virtual planning software, such as Sicat Endo (Dentsply Sirona), has been specifically designed for assessing root canal anatomy and determining preoperative working length. A recent study highlighted the usefulness of 3D planning software and CBCT for evaluating root canal anatomy and working length determination, while reducing residents' stress levels (8). Another study compared the accuracy of 3D endo software in determining working length using preoperative CBCT scans and an electronic apex locator intraoperatively in human extracted teeth. The results found no statistical difference between the measurements but suggested that, for cases with a preoperative CBCT scan available, 3D software could accurately determine working length (9). The development of CAD/CAM technology has opened new horizons in dentistry, providing precision, aesthetics, and restorative procedures that consume less time (10).

The aim of the present case report was to demonstrate a step-by-step 3D treatment plan, from diagnosis to endodontic treatment and final CAD/CAM restoration of a severely damaged maxillary molar. In the literature, there are several case reports on the use of digital technologies in endodontics, including one involving a destroyed molar with a 14-month follow-up.

Report

A 38-year-old female patient presented to our clinic to complete the treatment that was started a year ago to save element 2.6. She reported no painful symptoms, only masticatory discomfort caused by coronal destruction. The patient wishes to finish the treatment that was interrupted for personal reasons. Clinical tests indicated negative results for palpation, percussion, and vitality, with no periodontal pockets, suggesting a previously initiated therapy and normal apical tissues. The clinical examination revealed a temporary distal occlusal restoration on tooth 2.6, associated with significant loss of dental substance. The vestibular, palatal, and mesial walls were still intact (Figure 1). The mesial marginal ridge has a crack caused by existing caries on the mesial surface. Clinically, there the remaining tooth structure was enough to allow field isolation and safe execution of endodontic treatment. The patient's consent was obtained, and her medical history was not contributory. PRICE 2020 guidelines were used to report the current case. The proposed treatment plan includes the following stages: initial CBCT scan, optical impression, digital treatment planning, performance of endodontic treatment, CBCT scan control, and final coronal restoration.

Initial CBCT Scan

A CBCT scan was performed using the Orthophos SL3D with a 5 x 5 cm 80 voxel

Figure 1
Initial situation. Clinical aspect of tooth 2.6. The presence of a provisional restoration and a significant level of coronal destruction can be observed.

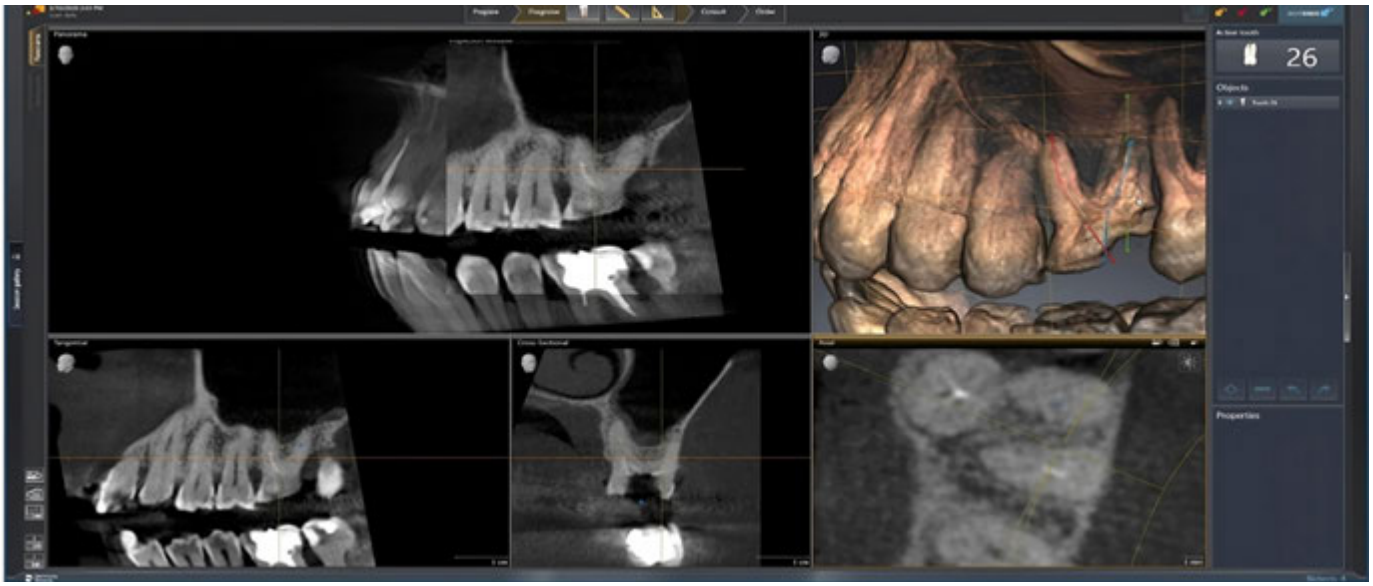
setting (Dentsply Sirona, Bensheim, Germany) and analyzed using Sidexis4 imaging software (Dentsply Sirona). The initial radiological examination demonstrated the presence of a previously incomplete endodontic treatment, with no evident apical hypodensity, except for slight hypodensity in the distal buccal root (Figure 2).

Digital Impression
An optical impression of the initial situation (Figure 3) was obtained using the PRIMESCAN system (Dentsply-Sirona, Bensheim, Germany) with Cerec SW 5.1 software. In this case, the access cavity was already created, making it unnecessary to export the optical print to the Sicat Endo application. For cases requiring access cavity planning, an optical impression is exported in .sxid format to the Sicat Endo application, which allows for the identification and stabilization of access into the root canals in a predictable manner, thereby reducing instrument stress.

Digital Endodontic Treatment Planning
The initial scan was then opened in the Sicat Endo application for analysis of the tooth's endodontic system and preliminary planning. The planning stages included: establishing the tooth for analysis (in this case, tooth 2.6), determining the tooth's axis, and tracing the four root canals (MB1, MB2, DB, P) from the occlusal surface to the apex for each canal. The Endoline function was utilized with the aid of the two Endoview windows, allowing for 360-degree image rotation around the Endoline. This facilitated necessary corrections to ensure that the Endoline was centered on the root canal along its entire length. The lengths of the four canals were measured simultaneously during the tracing process (Figure 4).

Performing the Endodontic Treatment
Endodontic treatment was carried out using the Zumax 3200 operating microscope (Zumax, China) for photo and video documentation of the treatment stages. After anesthesia with Ubistesin Forte (4% Articaine with 1:100,000 epinephrine; 3M Deutschland GmbH, Germany), rubber dam isolation was achieved using the KKD®

Figure 2
Initial CBCT. Radiographic examination within the SICAT ENDO application. The presence of an incomplete endodontic treatment is observed.



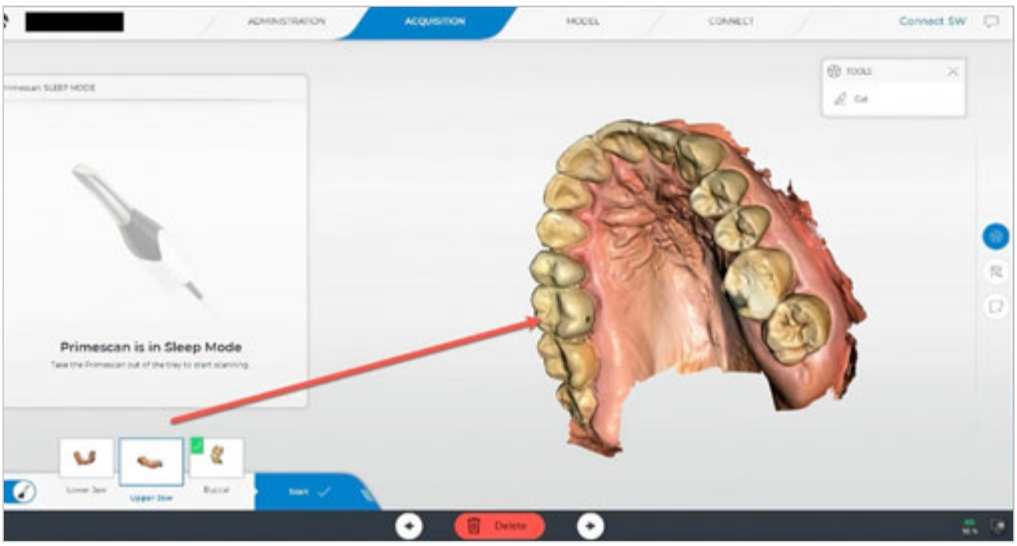


Figure 3
Optical impression of the initial situation.

Figure 4
Image during the planning of endodontic treatment in the Sicat Endo application. The white arrows indicate the usage of Endoline for determining the precise route and length of the root canal.

Rubber Dam Starter Kit (KKD, Ellwangen, Germany) and a soft clamp (Kerr, USA) for fixation. All existing temporary filling materials were removed (Figure 5A), and four root canals were located using the Satelec P5 Newtron XS system with the Endosucces loop kit (Acteon Group, UK). Following the removal of previous obturation materials, cleaning and shaping were completed with rotary system files (Dentsply-Maillefer).

The ATR Teknika motor (Dentsply - Maillefer) was used with a specific program for the ProTaper system, alongside the apex locator Raypex 6 (VDW, Germany) (Figure 5B). Disinfection involved alternating irrigation with 2.5 ml of 5.5% sodium hypochlorite (NaOCl) and 17% ethylenediaminetetraacetic acid (EDTA) between each instrument using a plastic syringe and a 30G NaviTip (Ultradent Products Inc.). A final disinfection was carried out with 5.5% NaOCl and 17% EDTA, activated three times for 20 seconds with ultrasonic activation (Figure 5C).

The four gutta-percha cones were calibrated according to the working length, the diameter of the last instrument used, and the apical diameter. Obturation of the root canals was performed using gutta-percha points and AH Plus sealer (Dentsply Detrey, Konstanz, Germany) (Figure 5D) with the warm vertical condensation technique using the BeeFill 2 in 1 system (VDW, Mu-

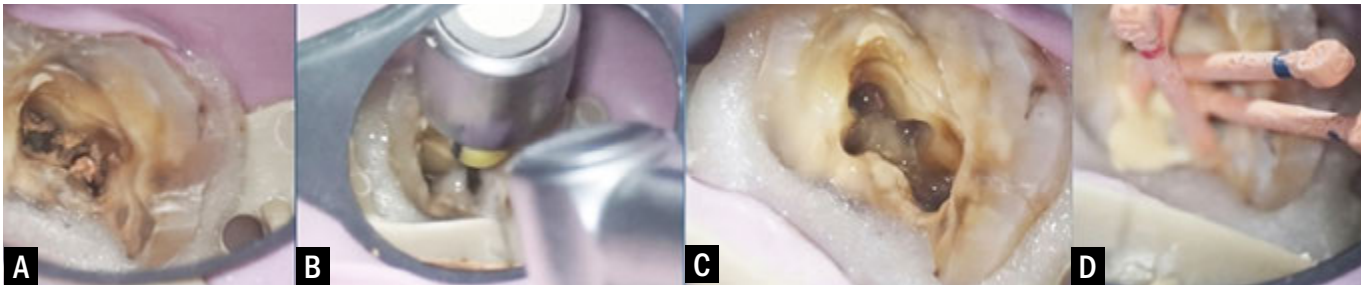


Figure 5
Images during the endodontic treatment. **A)** Identification of the entrances to the root canals. **B)** Canal preparation. **C)** Final irrigation. D) Placement of gutta-percha cones loaded with sealer.

nich, Germany) and FANTA gutta-percha pluggers (FANTA, China) calibrated for each canal. After completing the root canal filling, the pulp chamber was cleaned with isopropyl alcohol to remove remnants of the sealer. The pulp chamber was sealed with flowable composite following the classic adhesive protocol (acid etching, thorough washing with light pressure, adhesive application, photopolymerization, flow composite application, photopolymerization, gel application to inhibit the oxygen layer, photopolymerization, and gel washing).

Control CBCT Scan

At the end of the endodontic treatment, a new control CBCT scan (5x5 cm and 80 voxels) was performed with Orthophos SL3D for three-dimensional evaluation of the results. The scan was opened in the SICAT ENDO application, and the same steps as described in the planning stage were followed. The analysis confirmed the successful obturation of all four canals (Figure 6).

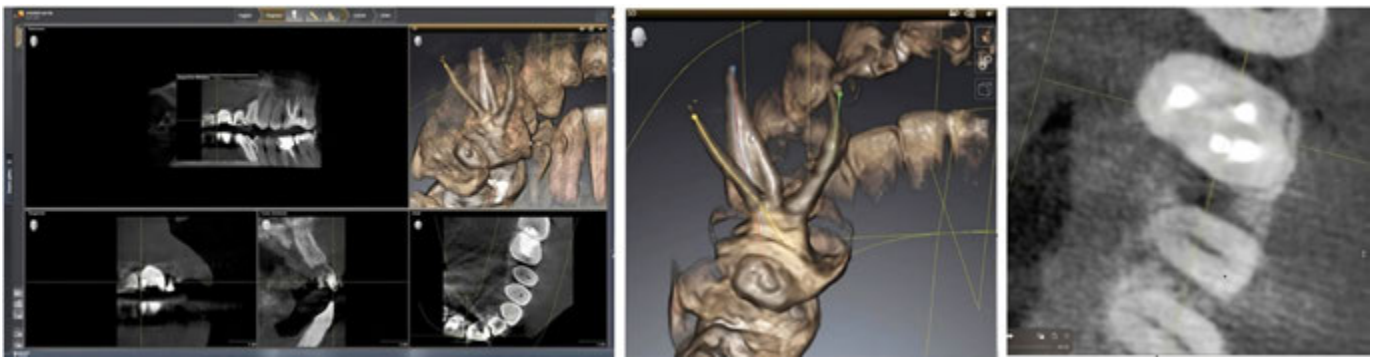
Figure 6
Control CBCT. Three-dimensional control of root canal obturation using the SICAT application.

Final Coronal Restoration

After radiological confirmation of the endodontic treatment, the tooth was prepared for the final coronal restoration. A type V endocrown preparation was chosen for the current case. (10) This type of preparation offers multiple advantages for molars, as it eliminates the need for fiberglass and composite pivot reconstruction, removes the necessity for classic crown preparation, maximizes preservation of remaining hard tissues, and provides proven mechanical resistance and periodontal protection.

The Cerec Primscan system with SW 5.1 was utilized for the digital protocol, which included the following stages: optical impression, model creation, edge delineation of the preparation (Figure 7), preparation design, and milling process (Figures 8A, B). The preparation was milled using the MCXL machine from an Emax LT A2 C14 cube (IvoclarVivadent, Lichtenstein).

Following the milling stage, the crown processing protocol was performed: sprue removal with a ceramic burn, intraoral probe use, finishing and polishing, ultrasonic cleaning in isopropyl alcohol for 1 minute, glazing and make-up, and crystallization in the Programat CS furnace (IvoclarVivadent, Lichtenstein) using the Crystal Glaze program. Subsequently, the final restoration was cleaned with Ivoclean (IvoclarVivadent, Lichtenstein) and conditioned with Prime Bond and Etch (IvoclarVivadent, Lichtenstein) for 60 seconds, washed with water, air-jet dried, and



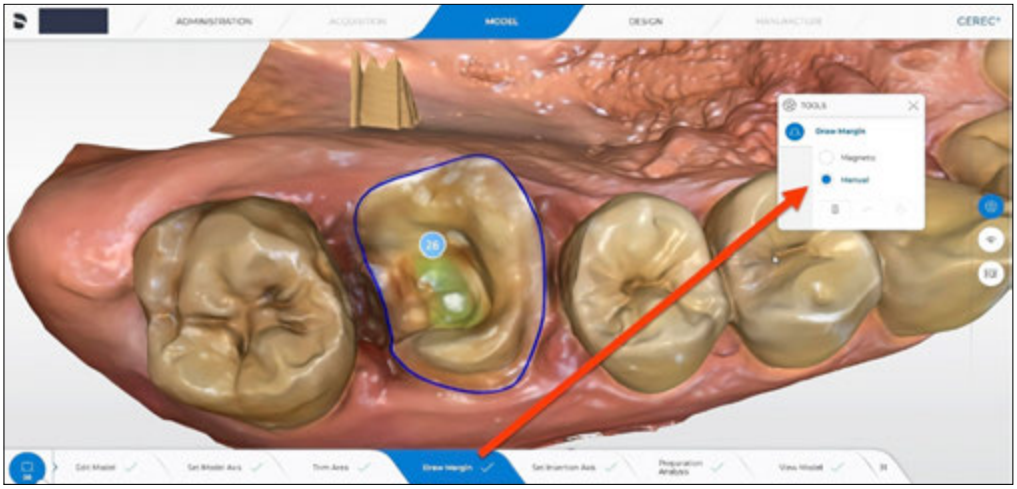


Figure 7
Final restoration using the CEREC system. MODEL stage - outlining the preparation.

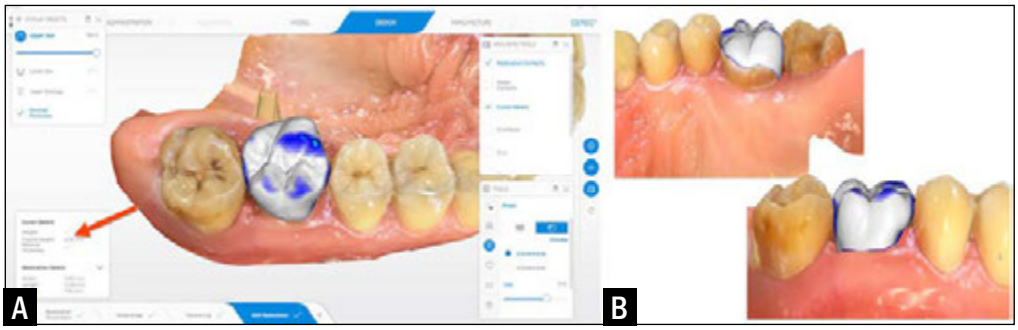


Figure 8
Final restoration using the CEREC system. DESIGN stage. A) Verifying the crown thickness at the Fissure Height. B) The final appearance of the crown project after applying the F.O.C.C. (Fissure - Occlusion - Contour - Contacts) protocol.

treated with Helio Bond adhesive (Ivoclar-Vivadent) (Figure 9A). Without removing the rubber dam isolation, the ceramic crown was cemented using the NX3 kit (Kerr, USA), with a dual core yellow color resin chosen (Figure 9B). At the conclusion of the clinical protocols, the restoration was precisely sealed with correct contact points (Figure 9C). At the four-year follow-up, the tooth was found to be fully functional, with no radiographic lesions or clinical signs and symptoms (Figure 10).

Discussion

The use of digital technologies offers the possibility of a personalized digital workflow for endodontically treated teeth in a single session, bringing numerous benefits. Santos et al. (12), in their case report using a CAD/CAM system, revealed the importance of a good restoration, with margins that integrate excellently and respect magnificent aesthetics. Segundo et al. (13) reported the benefits of a digital workflow for restoration with the CAD/CAM system and how aesthetic results with natural morphology can be achieved.

Radiological examination is an essential component of the diagnostic protocol, planning, and execution of any endodontic treatment. Although periapical radiography has been a source of radiological information for decades, these types of radiographs have clear limitations imposed by their 2D format (14). The additional information provided by CBCT may improve diagnostic accuracy and confidence, especially in teeth with previous endodontic treatment. It is important that patient radiation exposure be kept as low as possible while using a small field of view (15).

The Sicat Endo software (SICAT, Bonn, Germany) allows for 3D analysis of the endodontic system and planning for future treatment. In our daily clinical practice, we found that the mean time required for virtual planning using the Sicat Endo application varied between 5 to 8 minutes, depending on the number of root canals and the complexity of the case. This extra average time is fully justified because the

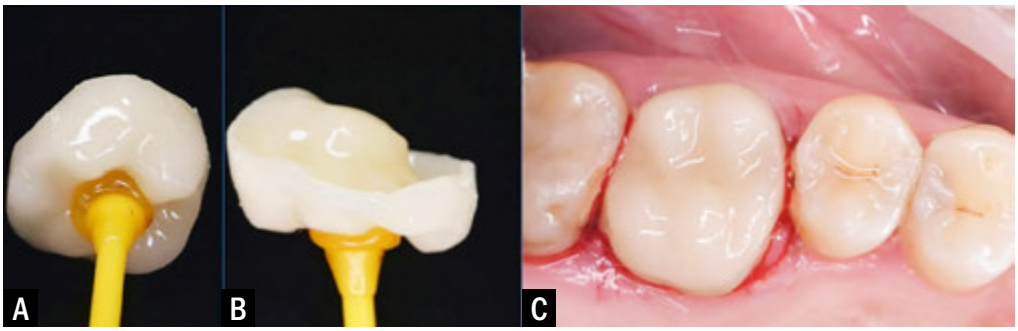


Figure 9A, B. The crown prepared for adhesive cementation. C. The immediate clinical appearance after cementation.

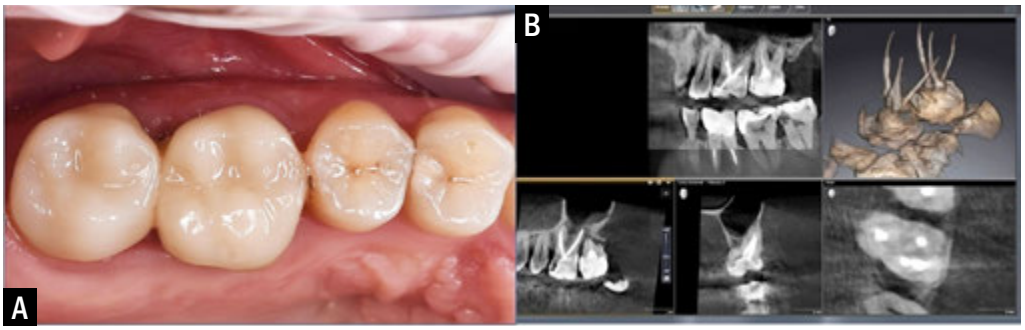


Figure 10 Clinical and radiological appearance at the 4 years follow-up.

duration of actual endodontic treatments has been reduced by 20-30 minutes due to the additional information that this 3D planning provides to the endodontist.
According to the authors, Sicat Endo is the application that "turned on the light in the darkness of the root canals". The use of this program, which can be utilized for any type of CBCT, provides answers for the most challenging endodontic treatments. Access design planning allows for the identification of the area in which to create the access cavity with minimal sacrifice of tooth structure and without additional stress on the instruments. In this manner, it is possible to identify all root canals in a 3D plane, with the possibility of 360-degree visualization. Direct restoration methods (reinforced composite obturation or non-root pivot) do not pose problems from the standpoint of being performed in the same session as the endodontic treatment; they fit seamlessly into the concept of "one-session dentistry."
The situation changes, however, in cases of teeth with extensive coronal destruction that require indirect restorations, which traditionally necessitate collaboration with a dental laboratory and an additional session. In these situations, the CEREC system proves its value by allowing all-ceramic restorations to be made in the same session within an acceptable time frame of 60 to 90 minutes.
More cleaning was planned through a rotary system that allowed for greater enlargement of the root canal and the contaminated walls, as the case had been initiated a year ago by another dentist and was already necrotic. The clinical approach was completed in a single session due to the absence of pain upon percussion; the patient only expressed discomfort due to the loss of coronal dental structure caused by the unfinished endodontic treatment.
The limitation of the current study is a single case. Usually, multiple cases with different diagnostic challenges and longer follow ups may better give idea on the reliability of performed treatment (16-18).

Conclusion

Current case report has shown successful outcomes even after 4 years follow up. The use of these technologies enhances the quality, predictability, and ergonomics of endodontic treatments, eliminating many causes of endodontic treatment failures. The economic benefits are also significant for both the dentist and the patient. With the use of digital workflow and the tech-

nology, correct diagnosis, planning, endodontic treatment, and definitive restoration through the CAD/CAM system are achieved. The approach and detailed protocol described in this case report can be easily adopted in a single session in a clinical dental practice using CBCT, Sicat Endo software, and the CAD/CAM system. The advantages of a single visit and immediate reconstruction include a reduction in the potential for microleakage between treatment visits and coronal leakage between appointments.

Clinical Relevance

This case report highlights the successful application of advanced digital technologies in endodontics and restorative dentistry, demonstrating the effective use of CBCT and Sicat Endo software for treatment planning and root canal identification. The one-session endodontic treatment of a maxillary molar, followed by a CAD/CAM-fabricated crown using pressed lithium disilicate material, resulted in a favorable four-year follow-up with no complications. This underscores the importance of integrating modern techniques for enhanced diagnostic accuracy and long-term success, serving as a valuable reference for clinicians in similar cases.

Confict of Interest

Authors deny any conflicts of interest.

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Cari Amici, Soci e Colleghi,
il mio mandato come Presidente della SIE volge al termine, è stato, è e continuerà ad essere un grande onore e anche una grande fatica cui mi sono dedicato con tutto il mio impegno e le mie capacità.
Voglio esprimere la mia gratitudine a tutti i Soci Attivi per la fiducia accordatami e per i preziosi consigli e valutazioni che molti hanno condiviso con me e a tutti i membri delle Commissioni e ai Responsabili di Macro Area per l'importante lavoro compiuto.
Il Consiglio Direttivo ha svolto un lavoro complesso e impegnativo in una situazione difficile di transizione da una segreteria interna a una esterna. Sono emerse dialettiche anche serrate di confronto che hanno fatto emergere visioni differenti sul futuro della società, tuttavia, l'interesse per il bene della SIE ha sempre prevalso nelle situazioni contingenti consentendoci di ottenere significativi risultati. Ringrazio tutti i membri del CD per l'impegno e la franca esposizione delle proprie idee sempre nel rispetto reciproco, in particolare devo ringraziare il nostro Segretario, Katia Greco, per la dedizione con cui ha svolto una davvero ingente mole di ottimo lavoro.
Sono orgoglioso di aver riportato la SIE sul territorio con tantissime **iniziative locali** che sono fiorite e hanno dato un riscontro di partecipanti davvero superiore alle aspettative, segno sicuro che esiste un grande interesse e che la strada intrapresa è quella giusta. Sono certo che sapremo sviluppare con qualità e varietà l'offerta formativa locale adeguando come necessario anche la struttura stessa della Società per essere più presenti sul territorio.
A livello di partecipazione, i nostri **webinar** 2024 hanno dato risultati davvero eccezionali, permettendoci di raggiungere tantissimi Colleghi soprattutto al di fuori dell'area strettamente SIE. Sono anche sicuro che i risultati di queste iniziative si vedranno compiutamente in tempi lunghi e non nel breve periodo, serviranno idee, coerenza, determinazione e l'aiuto di tutti.
La SIE festeggia quest'anno il **50° anniversario della sua fondazione**, abbiamo la certezza di aver fatto un buon lavoro e anche la consapevolezza di essere incappati in alcuni errori che, magari a causa delle congiunture dei tempi che viviamo, ci hanno condizionato più pesantemente di quanto sarebbe stato lecito aspettarsi. La SIE deve ripartire da questo traguardo con una profonda e determinata volontà di rinnovamento che deve basarsi su un fondamentale coinvolgimento di quei Soci Attivi che, pur avendo ormai maturato esperienze significative, sono più giovani ed esprimono idee, progetti e determinazione utili alla Società. Investire su una nuova classe dirigente di responsabilità può significare per la SIE, oltre che la base per progredire in maniera importante nella sua necessaria evoluzione, anche un fondamentale richiamo per quei giovani Colleghi che si avvicinano o crescono nelle nostre specialità endodontiche e di cui la Società ha bisogno per la sua crescita e per il necessario ricambio generazionale.
Il **bilancio 2023**, che partiva con un pesante handicap, si è chiuso invece con un leggero attivo grazie a una politica mirata di contenimento dei costi e di ottimizzazione delle risorse. Questa linea di azione è proseguita nell'anno in corso e l'obiettivo ragionevole per il bilancio 2024 è quello del pareggio. Le prospettive riportate dai nostri consulenti ci rassicurano in tal senso, ma sappiamo bene che il risultato del congresso nazionale, in termini di ricavi e costi, influirà sui risultati finali ed è quindi molto importante partecipare e far partecipare.
Quest'anno le strategie di comunicazione e pubblicizzazione del congresso sono state veramente tante, pressanti e diversificate, siamo fiduciosi che un evento così bello e interessante avrà il suo auspicato riscontro.
La nostra segreteria esterna, MV Congressi, ha avuto bisogno di un lungo periodo di rodaggio per entrare nelle dinamiche di una società scientifica così articolata come la SIE, ci sono state difficoltà e positività, ma, indubbiamente, ha dimostrato professionalità, disponibilità, dedizione e spirito di collaborazione per cercare di superare insieme tutti gli ostacoli e le criticità gestionali e finanziarie che hanno caratterizzato il biennio.
Il Consiglio Direttivo sta comunque valutando con attenzione tutte le opzioni che possano garantire miglioramento dei servizi e contenimento dei costi in un'ottica di gestione attenta delle risorse.
Il **Giornale Italiano di Endodonzia**, sotto l'attenta guida di Sandro Rengo, nel 2024 conferma il risultato storico conseguito lo scorso anno e vede incrementato il valore di impact factor a 0.5: è una importante certezza che il mondo ci invidia!
Mi rimane un ultimo particolare ringraziamento alle aziende che, con il loro sostegno e la fattiva disponibilità, aiutano la SIE a svolgere con successo la propria mission di formazione scientifica e culturale così importante per tutti noi.
Un augurio, infine, alla nostra SIE di essere sempre il punto di riferimento a tutti i livelli dell'Endodonzia italiana e nel mondo, con la certezza personale di aver ricevuto tantissimo, come tanti altri Soci Attivi, dalla nostra Società e di dover quindi essere sempre pronto a dare per il bene della SIE.
Un saluto affettuoso e commosso. Vi aspetto a Roma per festeggiare inSIEme i primi cinquanta anni della nostra Società Italiana di Endodonzia.

Mario Lendini

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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.

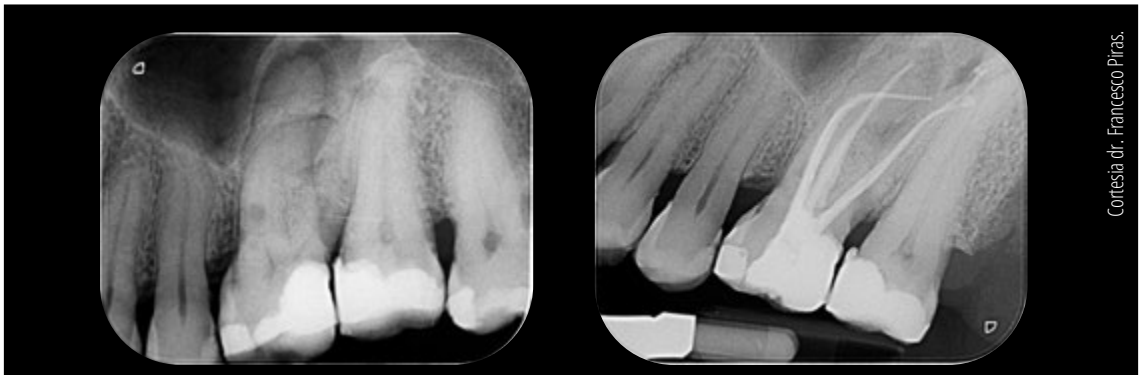
LA COMMISSIONE ACCETTAZIONE SOCI

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

Approccio minimal intervention



Cortesia dr. Francesco Piras.

Il primo molare superiore di sinistra presenta un quadro clinico di parodontite apicale cronica. La radiografia endorale evidenzia un'area osteolitica periradicolare e un'anatomia complessa a carico della radice mesiale dell'elemento. È inoltre visibile una modesta area di riassorbimento a carico della radice mesiale.

La preparazione dei canali radicolari e la loro conicità finale sono il punto chiave per un'adeguata detersione e otturazione tridimensionale; oggi questi importanti passaggi sono garantiti da un approccio di minimal intervention grazie ai moderni strumenti endodontici, le nuove leghe, e grazie ad adeguate sequenze, estremamente efficaci nel risparmiare struttura dentale.
La sistematica B-4U è composta da 5 strumenti con conicità massima .05 e diametro massimo coronale di 1 mm, assicurando così la minima asportazione di dentina e la maggiore preservazione di tessuto sano in corrispondenza di quelle aree canalari cruciali per la resistenza a lungo termine dell'elemento trattato.
Lo strumento, inoltre, in virtù della lega in Ni-ti trattata termicamente di cui è composto e della sua geometria (sezione romboidale con due angoli di taglio) risulta estremamente flessibile e resistente alla fatica ciclica, particolarmente adatto alla sagomatura di canali curvi e anatomie canalari complesse.

Caso clinico

Vista la complessità anatomica, la sequenza B-4U si rivela essere indicata per una sagomatura minimamente invasiva di questo elemento, con l'obiettivo di conservare le curvature radicolari e la dentina pericervivale.
Una volta eseguita correttamente la cavità d'accesso si irriga la camera pulpare con ipoclorito di sodio e si introduce un K file 10 precurvato nel canale palatino portandolo delicatamente a lunghezza di lavoro. Una volta che quest'ultimo risulta libero di muoversi a tale lunghezza e che la pervietà del forame è stata garantita, si prepara il glide path meccanico utilizzando lo Starter fino al raggiungimento della lunghezza di lavoro. A questo punto si può procedere con la sagomatura del canale senza alcun rischio, avendo già garantito un glide path sicuro, la lunghezza di lavoro e la pervietà apicale.
Con la camera pulpare riempita di ipoclorito di sodio al 5,25% si inizia a strumentare con Starter L. La stessa procedura utilizzata con Starter L viene ripetuta con il Finisher finché quest'ultimo non raggiunge la lunghezza di lavoro con uno o più passaggi.
Quando il Finisher esce dal canale e le lame apicali sono cariche di detriti si può decretare il raggiungimento della corretta sagomatura e il canale è pronto per l'otturazione.
Dopo aver terminato lo shaping con il Finisher e aver eseguito la prova di confluenza,
un sistema carrier based viene selezionato per l'otturazione canalare rappresentando fra quelli a disposizione, grazie alla sua facilità di utilizzo alla sua versatilità, una tecnica molto efficace per l'otturazione di canali lunghi, stretti e curvi.

GUIDELINES FOR AUTHORS

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

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

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

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

Ethical guidelines

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

Authorship and Acknowledgements

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

Manuscript preparation

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

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

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

Manuscript Types Accepted

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

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

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

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

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

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

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

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

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

Manuscript Format

The **official language** of the publication is **English**. It is preferred that manuscript is professionally edited. All services are paid for and arranged by the author and use of one of these

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

Structure
All manuscripts submitted to Giornale Italiano di Endodonzia should include Title Page, Abstract, Main Text, References, Clinical Relevance, Conflict of Interest, Acknowledgements, Tables, Figures and Figure Legends as appropriate.
Title Page should bear:

I. Title, which should be concise as well as descriptive (no more than 150 letters and spaces);
II. Initial(s) and last (family) name of each author;
III. Name and address of department, hospital or institution to which the work should be attributed;
IV. Running title (no more than 30 letters and spaces);
V. Three to five key words (in alphabetical order);
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.

Abstract for Clinical Articles should be no more than 250 words using the following structure.
Aim: give a clear statement of the main aim of the report and the clinical problem which is addressed.
Methodology: describe the methods adopted.
Results: give the main results of the study.
Conclusions: state the primary conclusions of the study.

THE STRUCTURE

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 appropri-

ate 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. Giornale Italiano di Endodonzia uses **double blinded review** which menas that the names of the reviewers will thus not be disclosed to the author submitting a paper and the name(s) of the author(s) will not be disclosed to the reviewers. To allow double blinded review, please submit your main manuscript and title page as separate files.
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 Rema-

tology; (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 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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