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RDE
Restorative Dentistry & Endodontics

Research Articles

Case Report

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Aims and Scope

The *Restorative Dentistry and Endodontics* (officially abbreviated as Restor Dent Endod; RDE) is a peer-reviewed and open access journal providing up-to-date information regarding the research and developments on new knowledge and innovations pertinent to the field of contemporary clinical operative dentistry, restorative dentistry, and endodontics. In the field of operative and restorative dentistry, the journal deals with diagnosis, treatment planning, treatment concepts and techniques, adhesive dentistry, esthetic dentistry, tooth whitening, dental materials and implant restoration. In the field of endodontics, the journal deals with a variety of topics such as etiology of periapical lesions, outcome of endodontic treatment, surgical endodontics including replantation, transplantation and implantation, dental trauma, intracanal microbiology, endodontic materials (MTA, nickel-titanium instruments, etc), molecular biology techniques, and stem cell biology. RDE publishes original articles, review articles and case reports dealing with aforementioned topics from all over the world.

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History

RDE (eISSN 2234-7666) is the official journal of the Korean Academy of Conservative Dentistry and was renamed from the *Journal of Korean Academy of Conservative Dentistry* (pISSN 1225-0864; eISSN 2093-8179), which was first published in 1975. It was initially published once a year but became a biannual journal in 1986, a quarterly journal in 1999, and then a bimonthly journal in 2001. From 2012, the journal name was renamed, the official language of the journal was changed to English, and it is currently published quarterly. This journal is supported in part by a Grant from the Korean Federation of Science and Technology Societies funded by the Korean Government (MEST).

Distribution

Restor Dent Endod is not for sale, but is distributed to members of Korean Academy of Conservative Dentistry and relevant researchers and institutions world-widely on the last day of February, May, August, and November of each year. Full text PDF files are also available at the official website (https://www.rde.ac; http://www.kacd.or.kr), KoreaMed Synapse (https://synapse.koreamed.org), and PubMed Central. To report a change of mailing address or for further information contact the academy office through the editorial office listed below.

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Comparative study of the effectiveness of different bleaching agents on blood-colored extracted teeth and investigation of recoloring after bleaching: an *in vitro* experimental study

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ABSTRACT

Objectives: This study evaluated the efficacy of three distinct bleaching agents over time on blood-stained, devitalized teeth. Furthermore, the recoloring subsequent to bleaching will be monitored.

Methods: The study was conducted on 60 caries-free, unfilled, upper human incisors. The Freccia and Peters blood staining technique was employed, and four groups ($n = 15$) were identified: control, 35% hydrogen peroxide-treated, 37% carbamide peroxide-treated, and sodium perborate-treated groups. Color differences were measured using ΔE_{00}, ΔWI_D, L^*, a^*, and b^* values. To investigate tooth discoloration after bleaching, 10 unbleached teeth with three groups of 10 bleached teeth were compared by vine staining. The group of bleached teeth was restored immediately, another group waited one week, and the third group had sodium ascorbate applied and analyzed using one-way analysis of variance tests ($p < 0.05$).

Results: Among the groups, carbamide peroxide exhibited the most significant whitening during the 6-day bleaching process, followed by hydrogen peroxide and sodium perborate. Subsequent examination of the wine recoloring of post-bleaching samples demonstrated that bleached teeth exhibited a heightened propensity for recoloration in contrast to unbleached teeth. Notably, sodium ascorbate treatments for hydrogen peroxide neutralization and the wait-and-restore approach were not statistically significant in terms of preventing recoloration.

Conclusions: Sodium perborate is less effective and more time-consuming than hydrogen peroxide or carbamide peroxide for bleaching purposes. Carbamide peroxide is the most effective bleaching agent. The sodium ascorbate treatment and the wait-and-restore approach are ineffective in preventing recoloring. Bleached teeth have more discoloration than unbleached teeth.

Keywords: Carbamide peroxide; Hydrogen peroxide; Sodium perborate; Tooth bleaching; Tooth discoloration; Tooth staining

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INTRODUCTION

The advent of social media has served to accentuate the societal value and popularity of a beautiful smile and a healthy mouth [1]. More people are getting dental treatments for cosmetic reasons. The prevailing expectation among these patients pertains to the whiteness of the teeth rather than to the alignment, symmetry, shape, and proportionate appearance of the teeth, which are complementary to an aesthetic smile [2].

Color perception can vary from person to person. A multitude of factors, including skin, hair, and gum color, age, and sex, have been identified as potential contributors to variations in tooth color perception. Consequently, patient expectations regarding the whiteness of their teeth exhibit significant variability. In order to address this discrepancy in perception, the ideal tooth whiteness can be defined as a whiteness proportional to the individual's sclera [3,4].

The color of teeth depends on dentin tissue and enamel thickness/texture, which can change over time due to internal/external factors. Frequent consumption of chromogenic foods and beverages such as tea, coffee, cigarettes, and alcohol is known as an external factor. Internal discoloration may be local or systemic. Local causes include pulp necrosis, intrapulpal bleeding, pulp tissue residues following endodontic treatment, endodontic materials, coronal filling materials, root resorption, and aging. Systemic factors encompass metabolic disorders, fluorosis, genetic causes, and drug-induced staining [5]. Although discoloration resulting from different etiologies may necessitate disparate treatment strategies, diffuse discoloration of the entire dental arch can be addressed through micro-abrasion, office bleaching, home bleaching, or over-the-counter products [6]. Discoloration affecting a single tooth or multiple teeth in the smile line can also be treated with intra-coronal bleaching methods [7].

Bleaching treatments have historically utilized a wide range of materials and methodologies. Traditionally, agents such as oxalic acid, chlorine compounds, sodium peroxide, and sodium hypochlorite were employed; however, their efficacy in oxidizing chromogens has been deemed insufficient, coupled with concerns regarding their potential adverse effects on dental tissues [8]. Contemporary research has established that the most effective bleaching results are achieved with hydrogen peroxide (HP) concentrations between 5% and 35%. As a powerful oxidizing agent, HP is widely used across various sectors, including cosmetics, textiles, healthcare, and industry, facilitating tooth whitening through the oxidation of chromogenic compounds [9].

While current bleaching methods are regarded as safe, effective, and minimally invasive, potential adverse effects warrant consideration. Specifically, 30% HP is recognized as corrosive to both skin and ocular tissue.

Additionally, excessive application may harm the gums by penetrating the dentinal tubules, leading to increased sensitivity and potential root resorption [10,11]. In response to these concerns, sodium perborate (SP) and carbamide peroxide (CP) have emerged as preferred alternatives within dental bleaching practices [12].

A substantial body of research has established that the combination of SP and distilled water is effective for bleaching devitalized teeth while concurrently minimizing damage to periapical tissues. Upon reacting with water, SP decomposes to produce sodium metaborate and HP. The lower incidence of adverse effects associated with the SP-distilled water mixture, compared to the conventional HP gel, can be attributed to the higher pH characteristic of this reaction [13].

CP, typically available in concentrations ranging from 10% to 20%, is a widely utilized component in bleaching treatments. Upon reaction, CP undergoes a decomposition process that yields urea, ammonia, carbon dioxide, and HP. Specifically, 10% CP contains approximately 3.3% to 3.5% HP and 6.5% urea [14]. The presence of urea contributes to an alkaline environment conducive to the bleaching process. Carbopol is commonly employed as a carrier in CP gels, enhancing their stability and application. Furthermore, the incorporation of potassium nitrate and fluoride has been shown to mitigate dentin sensitivity, thereby improving the safety profile of CP gels in comparison to HP gels [15]. While both CP and SP gels present unique advantages and disadvantages, it is the HP in these formulations that facilitates the bleaching effect.

HP is recognized for its ability to oxidize discolored tissue and facilitate its removal from the tooth, accom-

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panied by a foaming effect. *In vitro* studies have also been conducted to assess the potential for HP to cause damage to dental tissues [16]. Research utilizing scanning electron microscopy has revealed the formation of microporosities, pits, and areas of erosion resulting from mineral loss, which correlate with the concentration of HP employed [17,18]. As the concentration of HP increases, significant demineralization of the tooth surface occurs, leading to the dissolution of the organic matrix and a reduction in calcium content [19].

The free oxygen radicals generated as by-products of the HP reaction possess unpaired, highly reactive electrons, which have been shown to interfere with the bonding process of dental resins [20]. Inadequate bonding following the bleaching procedure may negatively impact the aesthetic quality of restorations, complicating the subsequent recoloring of teeth [21]. The neutralization of these reactive free radicals is facilitated by saliva, with this process typically requiring an average duration of one week (ranging from 24 hours to 3 weeks). This time frame is conducive to the recoloring of affected teeth. Consequently, many dental practitioners recommend a "white diet" to their patients during this period [22]. Moreover, the use of products such as hydroxyapatite, fluoride, casein phosphopeptide, and antioxidant gels is common in dental clinics to neutralize the effects of bleaching agents and mitigate any post-bleaching complications [23,24].

In light of the existing literature, it can be asserted that the efficacy of bleaching treatments can be assessed based on their capability to alter tooth color, the extent of damage to adjacent tissues, and their effectiveness in preventing the recurrence of discoloration.

The primary objective of this study was to evaluate the efficacy of three different bleaching agents over time, both individually and in comparison to one another. A secondary objective was to examine the degree of discoloration present in bleached teeth. The null hypotheses for this study were articulated as follows:

(i) The bleaching agents under investigation do not differ from one another in terms of bleaching speed and overall effect.

(ii) No significant difference exists between bleached and unbleached teeth concerning post-bleaching recoloring.

(iii) The application of sodium ascorbate treatments for the neutralization of HP, along with the wait-and-restore approach method, did not demonstrate effectiveness in preventing recoloration of bleached teeth.

METHODS

This study received approval from the Research Ethics Committee of the Faculty of Medicine, Ege University located in Izmir, Turkiye (protocol: 21-3T/52). The sample compsed 60 non-carious human incisors extracted for periodontal reasons, obtained from the Oral Surgery Polyclinic of Faculty of Dentistry, Ege University. All selected teeth were caries-free, unfilled upper anterior incisors, devoid of surface abnormalities. Prior to the initiation of the study, the samples were meticulously cleansed of any debris using a soft-bristled brush and subsequently disinfected by immersion in a 10% formalin solution for 48 hours.

Following disinfection, endodontic access cavities were created, preserving 2 mm of hard tissue in the buccal wall. All root canals were shaped, disinfected, and filled by a single research dentist using a standardized method. Canal fillings were subsequently retracted 2 mm from the cementoenamel junction, and the apical area was sealed with glass ionomer cement (3M, Saint Paul, MN, USA). The samples were then placed in moist sponges and stored in an incubator maintained at 37°C with 100% humidity for a duration of 7 days. The initial color of the teeth was assessed using a dental spectrophotometer and the VITA scale (SpectroShade, MHT Optic Research AG, Zürich, Switzerland).

The staining of samples was performed according to the protocol established by Freccia and Peters [25]. The human blood used in this study was sourced from waste blood designated for destruction at the Biochemistry Laboratory, Faculty of Medicine, Ege University. Prior to the staining procedure, the samples were immersed in a 5.5% sodium hypochlorite solution (Microvem, Samsun, Turkiye) for 24 hours to facilitate the opening of dentinal tubules. Subsequently, the teeth were placed in tubes containing 5 mL of plasma-removed erythrocyte suspension and subjected to two daily centrifugation cycles at 3,400 rpm for 20 minutes. This staining procedure was repeated until the teeth attained a color classi-

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fication of A3 or darker on the VITA scale, which took a total of 12 days.

Following the staining procedure, the color of the samples was assessed against a white background using a dental spectrophotometer. The 60 samples were stratified and randomly allocated into four groups, each consisting of 15 samples, to ensure a balanced distribution of color values ranging from A3 to C4 on the VITA scale. The control group did not receive treatment with any bleaching agent. The first group (HP group) was treated with a bleaching gel containing 35% HP (Opalescence Endo, Ultradent Products Inc., South Jordan, UT, USA). The second group (CP group) received a bleaching gel containing 37% CP (Whiteness Super Endo, FGM Produtos Odontológicos, Joinville, Brazil). The third group (SP group) was treated with a SP-superoxol mixture, with the cavity sealed using polytetrafluoroethylene tape (Table 1).

The bleaching materials were refreshed every 2 days, and the color of the teeth was measured using the dental spectrophotometer at consistent times, in the same location, and under comparable daylight conditions each day for a duration of 6 days. Color measurements were conducted three times for each tooth, and the mean value was subsequently recorded.

To evaluate the color change following the bleaching process, the bleached teeth were stratified randomly into three groups, with an equal number of teeth (n = 10) treated with each of the three bleaching materials in each group. The rationale for utilizing stratified randomization lies in the varying free radical ratios of the bleaching agents, aiming to ensure that the return of color remained unaffected by these discrepancies. Group 1 was formed from teeth that had never undergone bleaching. In group 2, composite restorations were applied after soaking the teeth in a 10% sodium ascorbate solution for 1 hour. In group 3, the composite restorations were applied immediately following the bleaching procedure. Group 4 involved leaving the tooth cavities empty, filled only with sterile cotton pellets following the removal of the bleaching agent, for a duration of one week (Table 2).

At the end of this period, restorations were performed. Additionally, the teeth were immersed in red wine for 20 minutes per day over the course of 6 days [26]. The color of the teeth was assessed prior to exposure to the wine and subsequently compared to the color after the wine-tinting process.

The color change between samples was recorded in the CIE $L^*a^*b^*$ (Commission Internationale d'Eclairage $L^*a^*b^*$ color space) color system. The formula CIEDE 2000 ($\Delta E_{00} = (\Delta L'/K_L S_L)^2 + (\Delta C'/K_C S_C)^2 + (\Delta H'/K_H S_H)^2 + RT (\Delta C'/K_C S_C) (\Delta H'/K_H S_H)^{1/2}$) was utilized to calculate the color change between samples. The present study evaluated the bleaching rate of bleaching agents within and between groups over time and the total color

Table 1. Bleaching products and ingredients used

Group	No. of samples	Product	Ingredient
Control group	15	-	Cotton pellet moistened with distilled water
HP group	15	Opalescence Endo (Ultradent Products Inc., South Jordan, UT, USA)	35% Hydrogen peroxide gel
CP group	15	Whiteness Super Endo (FGM Produtos Odontológicos, Joinville, Brazil)	37% Carbamide peroxide gel
SP group	15	Sodium perborate-superoxol mixture	Mixture prepared with 10 g sodium perborate and 2 mL superoxide

Table 2. Processes applied to groups before recoloring with red wine

Group	No. of samples	Process
Group 1	10	Control group
Group 2	10	Composite restoration was performed after the teeth were kept in 10% sodium ascorbate for 1 hour
Group 3	10	Composite restoration was applied immediately after bleaching
Group 4	10	Composite restoration was performed after the bleaching agent was cleaned and kept in the cavity with sterile cotton pellets for 7 days

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change between groups. To this end, the ΔE_{00}, L^*, a^*, and b^* values were examined to determine the amount of daily bleaching within each group. A threshold ΔE_{00} value of 0.8 was taken as the detectability value and 1.8 as the acceptability value. As a complementary measure, the whiteness index (WI_D) values were calculated according to the CIELAB color system. $WI_D = 0.511L^* - 2.324a^* - 1.100b^*$ formula was employed to assess the level of witness within and between groups. In this study, the WI_D (ΔWI_D) was assessed using the whiteness 50%:50% perceptibility (WPT) and 50%:50% acceptability (WAT) thresholds, determined in previous research at 0.72 and 2.60 ΔWI_D units, respectively [26]. To assess recoloring post-bleaching, the color was measured with the same material and method, and the ΔE_{00}, L^*, a^*, and b^* values obtained were compared between groups.

The minimum sample size was established at 60 teeth, determined using G*Power for the comparison of three different bleaching agents, with an expected effect size of 80% at the $\alpha = 0.05$ significance level. All subsequent calculations were performed using IBM SPSS version 20.0 (IBM Corp, Armonk, NY, USA). The Shapiro-Wilk test was employed to assess the normality of the data distribution. When the normality assumption was satisfied for at least two groups, a one-way analysis of variance was conducted to ascertain whether there were statistically significant differences among the groups. Time-dependent intragroup changes were evaluated using Bonferroni correction, with a significance level set at $p < 0.05$.

RESULTS

In the intergroup evaluations, there was a significant difference between the groups in mean ΔWI_D, ΔE_{00}, L^*, a^*, and b^* values ($p < 0.05$) (Tables 3 and 4, Figures 1–5). The CP group exhibited the most significant whitening during the 6-day bleaching process (32.31 ± 12.62), followed by the HP group (22.86 ± 8.25) and the SP group (11.25 ± 4.40). The SP group demonstrated the least whitening among the groups. The WI_D measurements corroborated the ΔE_{00} values. The CP group exhibited the most substantial ΔWI_D (22.88 ± 9.57), followed by the HP group (20.65 ± 10.63) and SP group (6.98 ± 14.87), in that order. A statistically significant discrepancy was identified among the groups ($p < 0.001$). This outcome led to the rejection of the null hypothesis (i). Subsequent to the completion of the bleaching process, a significant difference was observed in the color returned to the bleached teeth in comparison to the

Table 3. Color change (ΔE_{00}) values of specimens over 6 days in each experimental group

Time point	Control group	HP group	CP group	SP group	*p*-value
CVB	3.42 ± 2.34	4.52 ± 3.16	4.67 ± 3.44	3.29 ± 2.27	0.419
ΔE_{00}_day 1	*	16.22 ± 8.78	24.51 ± 4.28	3.98 ± 2.64	<0.001
ΔE_{00}_day 2	*	16.29 ± 7.47	25.05 ± 4.86	7.28 ± 4.88	<0.001
ΔE_{00}_day 3	*	21.10 ± 7.53	25.88 ± 3.68	8.78 ± 3.86	<0.001
ΔE_{00}_day 4	*	21.99 ± 8.02	26.37 ± 3.57	9.88 ± 4.10	<0.001
ΔE_{00}_day 5	*	20.78 ± 8.04	26.18 ± 3.83	12.43 ± 4.53	<0.001
ΔE_{00}_day 6	*	22.86 ± 8.25	32.31 ± 12.62	11.25 ± 4.40	<0.001

Values are presented as mean ± standard deviation.
CVB, color values before bleaching.
Group definitions are provided in Table 1.
*The control group wasn't exposed to any bleaching agent, so the initial measurement values were considered constant.

Table 4. Whiteness index (WI_D) values before and after bleaching

Time point	Control group	HP group	CP group	SP group	*p*-value
ΔWI_D_day 1	3.67 ± 12.41	–2.90 ± 11.03	4.25 ± 11.75	–3.62 ± 8.07	0.112
ΔWI_D_day 6	3.67±12.41	20.65 ± 10.63	22.88 ± 9.57	6.98 ± 14.87	0.001

Values are presented as mean ± standard deviation.
Group definitions are provided in Table 1.

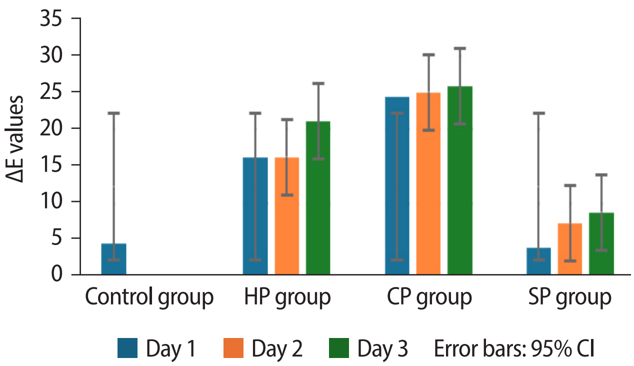

Figure 1. Daily change rates of mean color difference (ΔE) values. Group definitions are provided in Table 1. CI, confidence interval.

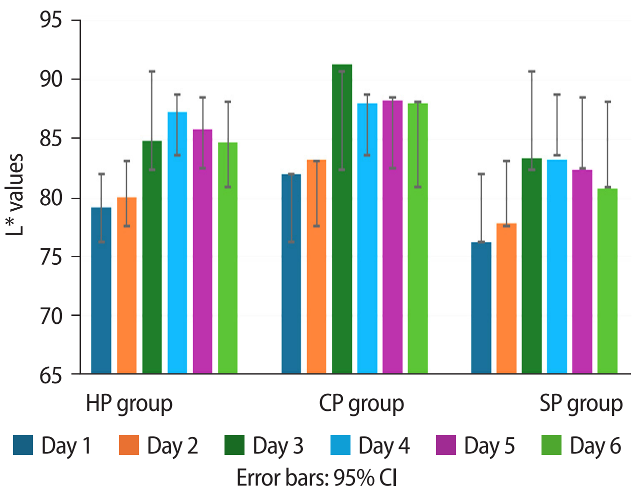

Figure 2. Daily change rates of mean L* values. Group definitions are provided in Table 1. CI, confidence interval.

control group, thereby confirming the rejection of the null hypothesis (ii). However, no significant difference was detected among the bleached teeth in groups 2 to 4, which led to the acceptance of the null hypothesis (iii) (Table 5, Figure 6).

DISCUSSION

The discoloration of the teeth following root canal treatment of the anterior teeth and the search for solutions to the aesthetic problems associated with it have been the subject of many studies. In 1982, Freccia and Peters [25] argued that "How well a bleaching method works depends on the cause of the discoloration." In light of the presented information, the decision was made in our study to utilize blood as the staining agent to simulate hemosiderin staining resulting from posttraumatic hemorrhage and necrotic pulp tissue, which is the most common staining agent [25].

Determining tooth color is a complicated process due to the varying surface structures and colors present on different tooth surfaces. Dental shade guides, which are commonly utilized in clinical settings for colorimetric analysis, are not objective methods due to their reliance on the subjective perceptions of the practitioner, the color of surrounding tissues, and ambient light, among other factors [27]. In our study, we employed a dental spectrophotometer to obtain objective, accurate, and reliable results.

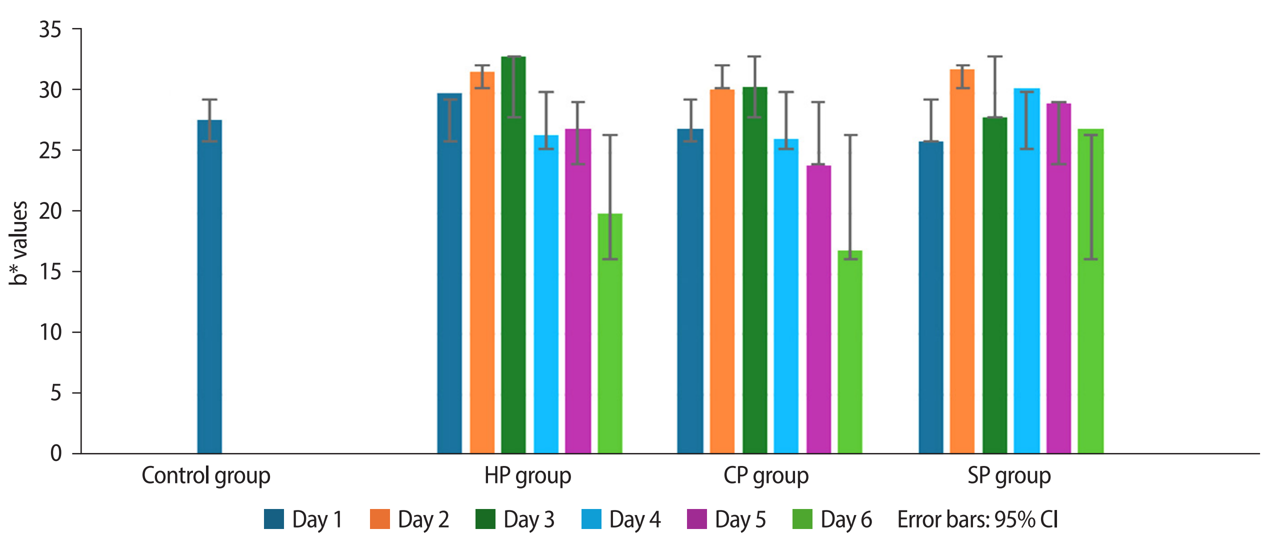

Figure 3. Daily change rates of mean b* values. Group definitions are provided in Table 1. CI, confidence interval.

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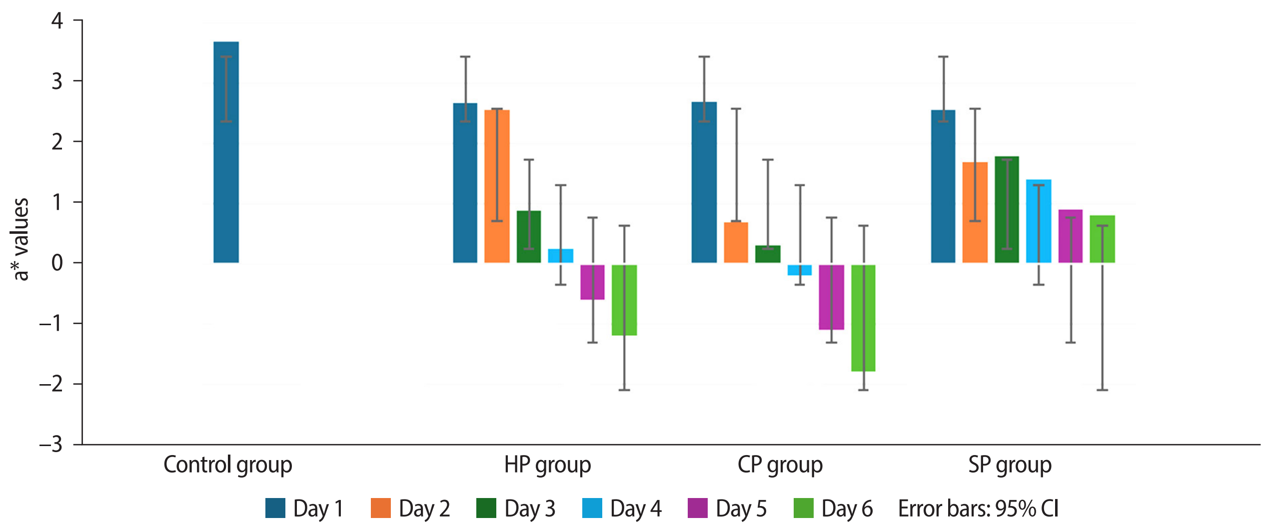

Figure 4. Daily change rates of mean a* values. Group definitions are provided in Table 1. CI, confidence interval.

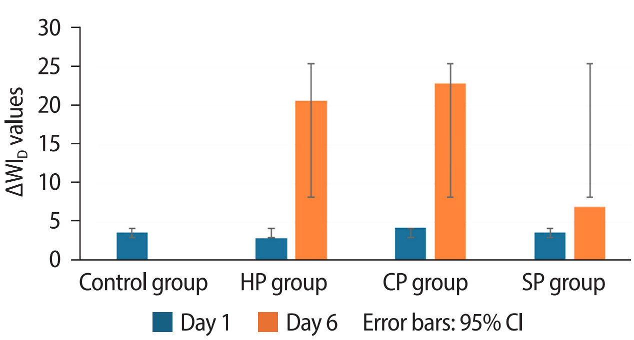

Figure 5. Whiteness index (WI_D) values before and after bleaching. Group definitions are provided in Table 1. CI, confidence interval.

In order to understand the variation in tooth color, it is necessary to understand the elements that determine color. Munsell defines color in terms of three elements: hue, value, and chroma. In contrast, the CIE defines color through a color system that uses three levels to express the coordinates of intersection (L^*: lightness; a^*: reddish-green; b^*: yellowish-bluish; ΔE: the amount of difference between two colors). Therefore, the identification of color by its coordinates facilitates more accurate results [28]. The ΔE value is subsequently calculated using these coordinates to express the difference between the two colors. According to extant literature, the decision was made to employ the CIEDE 2000 formula for the calculation of the ΔE value in the present study, as it has been demonstrated to accentuate more perceptible differences in comparison to the CIELAB formula [29]. Historically, if ΔE was determined to be greater than 3.3, it was considered sufficient to differentiate these two colors by the human eye. However, in this study, the current average threshold values of 0.8 for perceptibility and 1.8 for acceptability were employed as reference values [30].

The interpretation of the delta E value as a metric for change in color provides a robust indication of the efficacy of a bleaching treatment. Further validation of this metric is provided by the whitening index, which has been demonstrated to offer enhanced analytical power. The CIELAB-supported whitening index developed by Pérez *et al.* [27] has been evaluated in comparison to numerous other whitening indices and has been shown to be a reliable indicator. In our study, we have also examined the extent of tooth bleaching using the WI_D, providing a comprehensive assessment of the treatment's effectiveness.

A comprehensive examination of the study's outcomes reveals that the efficacy of three different bleaching agents varied over time. The most pronounced color change was observed in the Carbopol groups, followed by the HP and SP groups, respectively (Table 3, Figure 1). In a review of the results of studies comparing different bleaching agents conducted by Frank *et al.* [31], SP showed lower efficacy compared to CP and HP. However, no significant difference was found between CP and

Table 5. Evaluation of recoloration after bleaching

Color difference	Group 1	Group 2	Group 3	Group 4	*p*-value
ΔE_{00}	4.67 ± 3.44	19.78 ± 13.46	24.43 ± 14.01	24.35 ± 8.21	<0.001

Values are presented as mean ± standard deviation.
Group definitions are provided in Table 2.

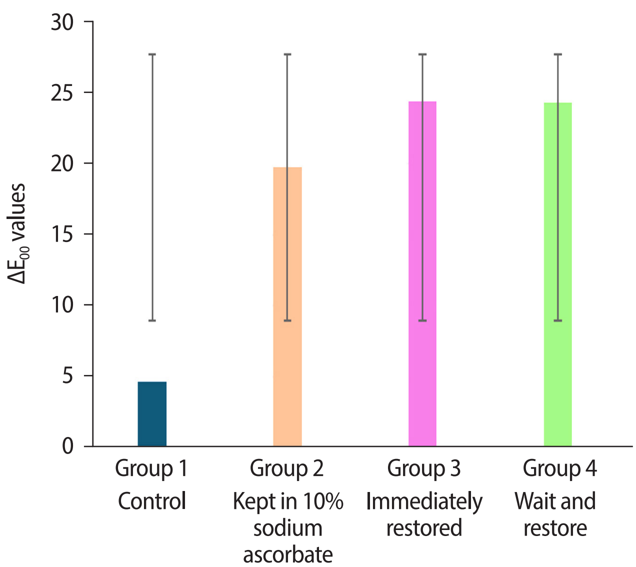

Figure 6. Amount of ΔE change of groups after recoloring. Group definitions are provided in Table 2. CI, confidence interval.

HP. If the results of our study are compared with this review, while SP obtained compatible results in terms of lower efficacy, CP showed more bleaching efficacy than HP in our study. In this respect, the results of the study are not compatible with the meta-analysis.

In an acidic environment, HP undergoes decomposition, yielding oxygen ions and hydroxyl free radicals. Conversely, within an alkaline environment (specifically between 9.5 and 10.8 on the pH scale), oxidation forms hydroperoxyl free radicals and enhances the bleaching effect [31,32]. Numerous studies have demonstrated that SP can effectively whiten the teeth without causing damage to the surrounding tissues. Nevertheless, a significant body of clinical studies has indicated that the bleaching effect is gradual [33]. In clinical settings, the preparation of the SP-superoxol mixture in the correct proportions and its subsequent application to the cavity without oxidation can pose a significant challenge. This may hinder the achievement of the desired degree of whiteness with SP.

In a clinical study, Keçeci [34] compared the efficacy of HP gel (Opalescence Endo) with that of a SP-superoxol mixture. The results indicated that while the HP gel produced visible whitening by day 2, the SP-superoxol mixture did not reach the desired level of whiteness until day 8. In our study, HP gel achieved maximum whitening by day 4; however, the SP-superoxol mixture failed to accomplish the desired whitening by day 8. These findings are consistent with the results reported in Keçeci's investigation.

The L^* value represents the lightness-darkness coordinate of color, and an increase in this value is anticipated throughout the bleaching treatment. In the present study, a statistically significant difference in L^* values was observed among the groups. The most notable increase in L^* value was recorded in the CP group, whereas the least significant increase occurred in the SP group.

In the context of bleaching treatments, a reduction in the b^* value is desirable to minimize the yellowish tones of the teeth. The results of this study indicate that the b^* value initially increased during the initial days of the bleaching process before beginning to decline after the third day. This initial increase may be attributed to the formation of by-products resulting from the breakdown of hemosiderin, a blood-derived substance, which contributes to the early yellowing observed during the bleaching process. Alternatively, yellow pigments may undergo decomposition at a later stage of the treatment.

The a^* value reflects the red-green coordinate of color, with the expectation that initially elevated values will decrease over time. A comparative analysis of the mean a^* values demonstrates a significant discrepancy between the study groups and the control group. Within each experimental group, the most pronounced decrease in mean a^* value is observed in the CP group, followed by the HP group, while the SP group exhibited the least significant reduction.

The outcome of the bleaching procedure is often assumed to be permanent; however, color reversion is a

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common occurrence. Howell [35] noted that "the more challenging the bleaching process, the more difficult it is to maintain color stability." Numerous studies have identified the presence of microscopic surface defects in enamel and the development of subsurface microporosity as the primary contributors to color recurrence [36].

In an *in vivo* study involving 26 bleached teeth, Deliper and Bardwell [37] monitored tooth color at 6-month intervals over a 2-year period, concluding that tooth color deteriorated by 19% due to the effects of devitalized bleaching. Conversely, an *in vitro* study conducted by Farawati *et al*. [38] found no significant difference in recoloring between bleached and unbleached teeth.

In the present study, however, a significant difference in recoloration was observed between bleached and unbleached teeth. This finding stands in contrast to the results reported by Farawati *et al*. [38], highlighting the ongoing debate regarding the durability of bleaching outcomes and the factors that influence color stability.

A significant challenge that impedes the effectiveness of bleaching treatments is the rapid recoloring that often occurs posttreatment, a phenomenon that is both undesirable and multifactorial in nature [27,28]. The present study aimed to determine whether there is a difference in color return between bleached and unbleached teeth by employing the wine-coloring method, which has been recognized in the literature as one of the most effective techniques for assessing color recurrence [26]. To achieve this objective, the study investigated whether the application of a sodium ascorbate solution to neutralize HP in bleached teeth could delay the return of color for up to 1 week.

In their study involving 72 bovine teeth, Türkün *et al*. [39] reported that the application of 10% sodium ascorbate gel for 60 minutes yielded optimal effects on bond strength following bleaching. Research on post-bleaching bond strength suggests that a delay of 24 hours to 3 weeks is advisable to mitigate the effects of HP on bonding efficacy. Freire *et al*. [40] found no significant difference in bond strength when comparing delayed bonding to immediate bonding in conjunction with the use of antioxidants.

Despite this, there remains a paucity of studies investigating the impact of sodium ascorbate on color stability after bleaching. The present study sought to ascertain whether sodium ascorbate indirectly influences recoloration by affecting energy exchange on the tooth surface and the sealing efficacy of composite restorations. Notably, an increased incidence of recoloring was observed in the bleached teeth group compared to the control group. Furthermore, no statistically significant differences were found between delaying restoration for one week to allow for HP neutralization, the application of sodium ascorbate as an antioxidant, or immediate restoration application.

It is important to highlight that the current study evaluated three distinct bleaching agents, all of which contained HP. The variation in bleaching efficacy observed can be attributed to the differing concentrations of HP within these formulations and the resultant by-products of the bleaching reactions.

CONCLUSIONS

The findings of this study indicate that HP, CP, and SP gels demonstrate significant variability in terms of bleaching speed and effectiveness, with CP exhibiting the highest bleaching efficiency. Regarding the issue of post-bleaching discoloration, it was noted that the application of sodium ascorbate or the neutralization of HP does not effectively mitigate recoloration. Additionally, bleached teeth displayed a greater tendency for recoloration compared to unbleached teeth.

In light of these findings and the distinct characteristics of the bleaching agents, particularly their varying HP concentrations and the subsequent alterations in residual HP levels, a new avenue for research has emerged. Future studies are planned to explore innovative materials that may impede color recurrence, thereby providing a comprehensive approach to the management of bleaching-induced discoloration.

CONFLICT OF INTEREST

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

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AUTHOR CONTRIBUTIONS

Conceptualization, Data curation, Formal analysis, Funding acquisition: Türkün M. Investigation, Methodology, Project administration, Resource, Software: Aladağ A. Supervision, Validation: Demirbaş A. Visualization: Arslan G. Writing - original draft: Arslan G. Writing - review & editing: All authors. All authors read and approved the final manuscript.

DATA SHARING STATEMENT

The datasets are available from the corresponding author upon reasonable request.

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How protocol, posts, and experience affect fracture detection in multi-rooted teeth using cone-beam computed tomography: an *ex vivo* experimental study

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ABSTRACT

Objectives: This study aimed to evaluate the influence of cone-beam computed tomography (CBCT) acquisition protocol, the presence of intraradicular metal post, and examiner experience on the detection of complete root fractures in multi-rooted teeth.

Methods: Twenty human molar teeth filled with gutta-percha were placed into artificial alveoli created in bovine ribs. The sample was divided into two groups based on the presence or absence of intraradicular posts in the distal roots. CBCT scans were obtained using four acquisition protocols with varying voxel sizes (0.28, 0.2, 0.125, and 0.80 mm). Following the creation of controlled fractures using a chisel and hammer, CBCT imaging was repeated, resulting in 160 images. Five examiners assessed the images using OnDemand software (KaVo Dental GmbH). Sensitivity, specificity, and accuracy were calculated for each examiner, CBCT protocol, and post-condition. Statistical comparisons were performed using Cochran's Q test and McNemar test, and a significance level of 5%.

Results: In teeth without metallic posts, sensitivity, specificity, and accuracy values exceeded 0.70, 0.70, and 0.80, respectively. However, the presence of metallic posts significantly reduced diagnostic performance, particularly in low-resolution protocols evaluated by less-experienced examiners.

Conclusions: CBCT acquisition protocols should be selected based on the presence of metallic posts to optimize root fracture detection in multi-rooted teeth. Examiner experience also plays a critical role in diagnostic accuracy.

Keywords: Cone-beam computed tomography; Examiner experience; Root fracture

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INTRODUCTION

Root fractures have a poor prognosis and are responsible for 10.9% of extractions of endodontically treated teeth [1]. Unfortunately, the diagnosis of teeth with prior endodontic treatment is a significant challenge for clinical examination, because root fractures have signs and symptoms similar to those of failed endodontic treatment or periodontal disease [2,3], and for radiographic interpretation, because of structures superimposition [4]. To aid in diagnostic thinking and clinical decision-making, cone-beam computed tomography (CBCT) may be indicated for cases in which clinical findings are suggestive of root fracture but radiographs provide negative or ambiguous evidence, or when there is no strong clinical evidence but radiographs raise the possibility of fracture [5,6].

Several factors, such as acquisition parameters, root filling, tooth anatomy, and examiner experience, may affect CBCT accuracy. The voxel size is the most investigated acquisition parameter since it directly influences image resolution. Diverse authors claim that higher resolution images are better for increasing exam sensitivity [7–10], but studies also show that the benefit of using a smaller voxel depends on the root filling [9,11,12]. The accuracy of CBCT diagnosis for root fractures may be compromised when radiopaque materials like gutta-percha and metallic posts are present in the root canal due to the formation of artifacts [13–17].

Multi-rooted teeth are the most compromised by root fractures [18]. Nonetheless, few studies investigated multi-rooted teeth [14,16,19–21], and only two of them investigated different acquisition protocols varying the voxel size [16,20]. However, in these two studies, the authors compared protocols across different CBCT systems, potentially introducing bias to their evaluations. Moreover, examiner experience plays an important role, as experienced examiners perform better in the assessment of root fractures [22,23]. However, the performance of students, especially undergraduates, is still overlooked [24], which may impair their development in clinical practice and radiological training for root fracture diagnosis.

Given the clinical challenges and the potential impact of root fractures on treatment outcomes, understanding the interplay between CBCT acquisition parameters, intraradicular materials, and examiner expertise is crucial for improving diagnostic accuracy. While existing studies have explored various aspects of root fracture diagnosis [24–26], gaps remain regarding multi-rooted teeth, the influence of voxel size within the same CBCT system, and the diagnostic capabilities of less-experienced examiners, such as undergraduate students.

Therefore, the objective of this study was to evaluate the influence of CBCT acquisition protocol, the presence of intraradicular metallic posts, and the examiner experience in detecting complete root fractures in multi-rooted teeth.

METHODS

Study design

An *ex vivo* experimental study was performed with 20 multi-rooted human teeth. The teeth were provided by the Department of Morphology of Federal University of Santa Maria, and the Institution's Ethics Committee approved the study protocol (No. 39486614.2.0000.5346).

Sample preparation

Each tooth was inspected under a magnifying glass (×3; Jieda Tools Co., Ltd, Xinyu, China) to confirm the absence of cracks and/or fractures. Endodontic access was performed with a spherical drill No. 1014 (KG Sorensen, Barueri, Brazil) and a conical drill with inactive tip No. 3082 (KG Sorensen).

The root canals were instrumented using the quarter-turn pull technique with K-files (Dentsply-Maillefer, Ballaigues, Switzerland), which consists of manual instrumentation to shape and prepare the root canal. The K-file was inserted into the root canal until resistance was felt, followed by a 90° clockwise rotation (a quarter turn) to engage dentinal walls, and then the instrument was withdrawn along the same path. The mesial canals were instrumented with 30 size K-files, and the distal canals were instrumented until 40 size K-files up to the working length. Each canal was frequently irrigated with a 2.5% sodium hypochlorite solution. The root canals were filled with Endofill sealer (Dentsply-Maillefer) and gutta-percha cones (Dentsply-Maillefer) by cold lateral compaction.

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The sample was randomly divided into two groups, and a metallic intraradicular post was inserted in half of the sample. To place the metallic post, the gutta-percha was removed from the coronal and middle thirds of the distal root using a #4 Gates-Glidden drill (Dentsply-Maillefer) and a #4 Largo drill (Dentsply-Maillefer). Metallic posts (Angelus, Londrina, Brazil) were inserted in the prepared roots, leaving at least 4 mm of gutta-percha inside the root.

All teeth were inserted into artificial alveoli, created using spherical drills, in bovine ribs, to simulate the alveolar bone [27]. The teeth were fixed to the artificial alveoli with wax (Asfer, São Caetano do Sul, Brazil) and plaster (Asfer). Root fractures were performed using a tapered chisel inserted in the pulp chamber and gently tapped with a hammer.

Image acquisition

The tomographic images were acquired using an OP 3D tomographic device (KaVo, Joinville, Brazil). The rib-teeth set was adapted to a three-dimensional printed jaw, surrounded by a 15-mm layer of wax in order to simulate soft tissues [28]. The mandible was stabilized to the CBCT device, and the field of view (50 × 50 mm) was adjusted to the right lower molar region.

Four acquisition protocols were used: low resolution (voxel, 0.28 mm; exposure time, 1.2 seconds; 3.8 mAs; 90 kV), standard-resolution (voxel, 0.2 mm; exposure time, 2.3 seconds; 18.4 mAs; 90 kV), high resolution (voxel, 0.125 mm; exposure time, 6.1 seconds; 38.4 mAs; 90 kV), and endo resolution (voxel, 0.085 mm; exposure time, 8.7 seconds; 54.8 mAs; 90 kV).

CBCT scans were performed before and after the fracture of the specimens, meaning eight acquisitions for each tooth, 160 acquisitions in total.

Image evaluation

CBCT acquisitions were exported in DICOM files and evaluated using the OnDemand software (KaVo Dental GmbH, Biberach an der Riß, Germany). All images were evaluated on the same computer (Intel i5; Intel Core i5-3570 CPU @ 3.40 GHz) and LED screen monitor (1,920 × 1,080 resolution, 23-inch Dell U2312HMt; Dell Ltda, Eldorado do Sul, Brazil), in a windowless room with subdued artificial lighting. All examiners were instructed to use the '1.5×' sharpen filter to evaluate the images. The brightness, contrast, and zoom settings were adjusted according to each examiner's preference. CBCT acquisitions were randomized using the randomizer.org website.

Five trained examiners (three postgraduate students in the Division of Oral Radiology and two third-year undergraduate dental students) evaluated all 160 files each. Training consisted of a 1-hour meeting to discuss the condition evaluated in the study (root fracture) and software manipulation. After assessing each DICOM, the examiner answered the question "Is there a root fracture?" using a 5-point Likert scale: "definitely yes," "probably yes," "uncertain," "probably no," and "definitely no."

Statistical analysis

Sensitivity, specificity, and accuracy values were calculated for each examiner, CBCT acquisition protocol, and the presence of intraradicular posts. To calculate the diagnostic test values, the Likert scale was dichotomized: categories 'definitely yes' and "probably yes" were combined as 'presence of root fracture,' and "uncertain," "probably no," and "definitely no" were combined as 'absence of root fracture.' The true diagnosis was compared among the variables using the Cochran Q test. Statistical analysis was performed with the SPSS software ver. 13 (SPSS Inc., Chicago, IL, USA). A significance level of 5% was used.

RESULTS

The sensitivity, specificity, and accuracy values for each examiner, CBCT acquisition protocol, and the presence of intraradicular posts are presented in Table 1. Teeth with metallic posts consistently exhibited lower diagnostic performance, particularly in low-resolution acquisition protocols. This effect was more pronounced for less-experienced examiners, whose sensitivity dropped to 0.40, under these conditions.

Table 2 highlights the percentage of correct diagnoses (hits) for each examiner, stratified by CBCT acquisition protocol and the presence of metallic posts. A statistically significant difference was observed in examiner 1's evaluations. For teeth with metal posts, the low-resolu-

Table 1. Values of accuracy, sensitivity, and specificity for each examiner according to acquisition protocol and presence of metallic post

Variable	Acc (E1)	Sens (E1)	Spec (E1)	Acc (E2)	Sens (E2)	Spec (E2)	Acc (E3)	Sens (E3)	Spec (E3)	Acc (E4)	Sens (E4)	Spec (E4)	Acc (E5)	Sens (E5)	Spec (E5)
With post															
Low resolution	0.75	0.80	0.70	0.95	0.90	1.00	0.90	0.80	1.00	0.65	0.40	0.90	0.60	0.40	0.80
Standard resolution	0.95	1.00	0.90	0.90	0.90	0.90	0.90	0.80	1.00	0.80	0.80	0.80	0.85	0.80	0.90
High resolution	0.95	1.00	0.90	0.95	1.00	1.00	0.90	0.80	1.00	0.90	0.90	0.90	0.85	0.90	0.80
Endo resolution	0.95	1.00	0.90	0.95	1.00	0.90	0.95	0.90	1.00	0.80	0.70	0.90	0.85	0.80	1.00
Without post															
Low resolution	0.95	0.90	1.00	0.95	0.90	1.00	0.95	0.90	1.00	0.85	0.70	1.00	0.90	0.80	1.00
Standard resolution	0.95	0.90	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.90	0.80	1.00	0.95	0.90	1.00
High resolution	0.95	0.90	1.00	1.00	1.00	1.00	0.90	0.90	0.90	0.80	0.90	0.70	0.85	0.70	1.00
Endo resolution	1.00	1.00	1.00	1.00	1.00	0.90	0.95	0.90	1.00	0.90	0.80	1.00	0.95	0.90	1.00

Acc, accuracy; Sens, sensitivity; Spec, specificity; E1, examiner 1; E2, examiner 2; E3, examiner 3; E4, examiner 4; E5, examiner 5.

tion protocol resulted in significantly fewer correct diagnoses (75%) compared to the standard-resolution (95%), high-resolution (95%), and endo-resolution (95%) protocols ($p = 0.028$). For teeth without metallic posts, diagnostic performance remained consistently high across all acquisition protocols, with accuracy values generally above 0.85 for all examiners. Notably, the endo-resolution protocol achieved 95% or higher accuracy for most examiners, emphasizing its superior diagnostic potential in this scenario. Figures 1 and 2 show axial cone-beam computed tomography slices of the sample teeth without and with post, respectively, acquired on the four protocols.

DISCUSSION

The diagnosis of root fractures remains a challenging task due to their non-specific clinical signs and symptoms and often limited radiographic findings, particularly for beginners in dentistry [22,23,27–31]. Although CBCT is more effective than two-dimensional imaging for detecting root fractures, its diagnostic accuracy is influenced by various factors, such as fracture orientation and width [32], the presence of intraradicular materials [11,17], and image acquisition protocol [17,21,32]. This study evaluated the effects of CBCT acquisition protocol, the presence of intraradicular metallic posts, and examiner expertise in diagnosing complete root fractures in multi-rooted teeth. The findings revealed that the diagnosis is significantly impaired by the presence of metallic posts, especially when low-resolution acquisition protocols are interpreted by less-experienced examiners. By addressing these underexplored areas, this study not only clarified conflicting evidence but also aimed to provide actionable insights for optimizing CBCT protocols and enhancing training in dental radiology.

The negative impact of metal posts in the diagnosis of root fractures has been reported in previous studies [33,34]. High atomic number materials create beam-hardening artifacts, which can obscure fracture lines or even simulate false fractures [15], jeopardizing the diagnosis. To overcome this adversity, it is recommended to use high-resolution protocols when root fracture is suspected. However, the concept of having “as high as possible” spatial resolution (here referred to as “endo-resolution”) invariably leads to an increase in radiation dose [35–37]. This reinforces the importance of tailoring the protocol to the specific diagnostic requirements, ensuring the lowest radiation dose that still provides sufficient image quality [5,38].

The influence of voxel size on root fracture diagnosis was the subject of study in several publications [24–26]. de Lima Moreno *et al.* [34] pointed out that the 0.3-mm voxel should be selected for teeth without root fillings, and the 0.2-mm voxel should be selected for teeth with the presence of metal posts. Likewise, Silveira *et al.* [9] demonstrated comparable diagnostic performance for 0.2- and 0.3-mm voxel resolutions in teeth without root fillings but superior performance with 0.2-mm voxel resolution for teeth with metallic posts. Thus, the selection of voxel resolution should be guided depending on

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Table 2. Percentage of hits for each examiner according to acquisition protocol and presence of metallic post

Presence of post	Acquisition protocol																			
	Low resolution					Standard resolution					High resolution					Endo resolution				
	E1	E2	E3	E4	E5	E1	E2	E3	E4	E5	E1	E2	E3	E4	E5	E1	E2	E3	E4	E5
With post	75%^{Aa}	95%^{Aab}	90%^{Aab}	65%^{Aab}	60%^{Aab}	95%^{Ab}	90%^{Aab}	90%^{Aab}	80%^{Aab}	85%^{Aab}	95%^{Ab}	95%^{Aab}	90%^{Aab}	90%^{Aab}	85%^{Aab}	95%^{Ab}	95%^{Aab}	95%^{Aab}	80%^{Aab}	85%^{Aab}
Without post	95%^{Aa}	95%^{Aa}	95%^{Aa}	85%^{Aa}	90%^{Aa}	95%^{Aa}	100%^{Aa}	90%^{Aa}	90%^{Aa}	95%^{Aa}	95%^{Aa}	100%^{Aa}	90%^{Aa}	80%^{Aa}	85%^{Aa}	100%^{Aa}	100%^{Aa}	95%^{Aa}	90%^{Aa}	95%^{Aa}

E1, examiner 1; E2, examiner 2; E3, examiner 3; E4, examiner 4; E5, examiner 5.
Different lowercase letters in a row indicate significant differences regarding the acquisition protocol. Different capital letters in a column indicate significant differences regarding the presence of post.

the material present inside the root canals. The findings of this study align with these observations, suggesting that a low-resolution protocol (voxel, 0.28 mm) is suitable for teeth without endodontic fillings to minimize radiation exposure, whereas higher resolutions (voxel, ≤0.2 mm) are preferable for teeth with metallic posts or root canal fillings. These results underscore the need to implement the ALADAIP (as low as diagnostically acceptable, being indication-oriented and patient-specific) principle [39] in clinical practice.

While the fractures in this study involved complete displacement of fragments, which could simplify diagnosis, examiner expertise emerged as a significant factor. Less-experienced examiners achieved lower accuracy, particularly when interpreting low-resolution protocols for teeth with metallic posts. This finding aligns with Gao *et al.* [22], who reported that experienced radiologists demonstrate superior diagnostic accuracy compared to graduate students. The lower accuracy of less-experienced examiners is probably related to factors such as limited familiarity with CBCT software [40], difficulty in distinguishing artifacts from fractures, and lack of exposure to complex radiological cases. These results highlight the critical role of expertise in imaging interpretation and emphasize the necessity for advanced CBCT training in graduation, particularly for challenging cases [31].

This laboratory study was designed to narrow the presence of bias to the only assessed variables: CBCT resolution, presence of metal post, and examiner experience. However, as with any *ex vivo* research, certain limitations must be acknowledged. First, laboratory conditions do not fully replicate the complexity of real-world clinical scenarios. In clinical practice, CBCT scans are often affected by patient movement, restorations, and prosthetic structures that can introduce additional image distortions and beam-hardening artifacts, which may obscure or mimic root fracture lines. Moreover, X-ray beam attenuation differs significantly between *ex vivo* and *in vivo* settings due to the presence of adjacent soft and hard tissues in the latter. As a result, laboratory images generally exhibit superior quality, with reduced noise and enhanced contrast compared to clinical scans. To simulate soft tissue attenuation and mitigate this discrepancy, the entire mandible was cov-

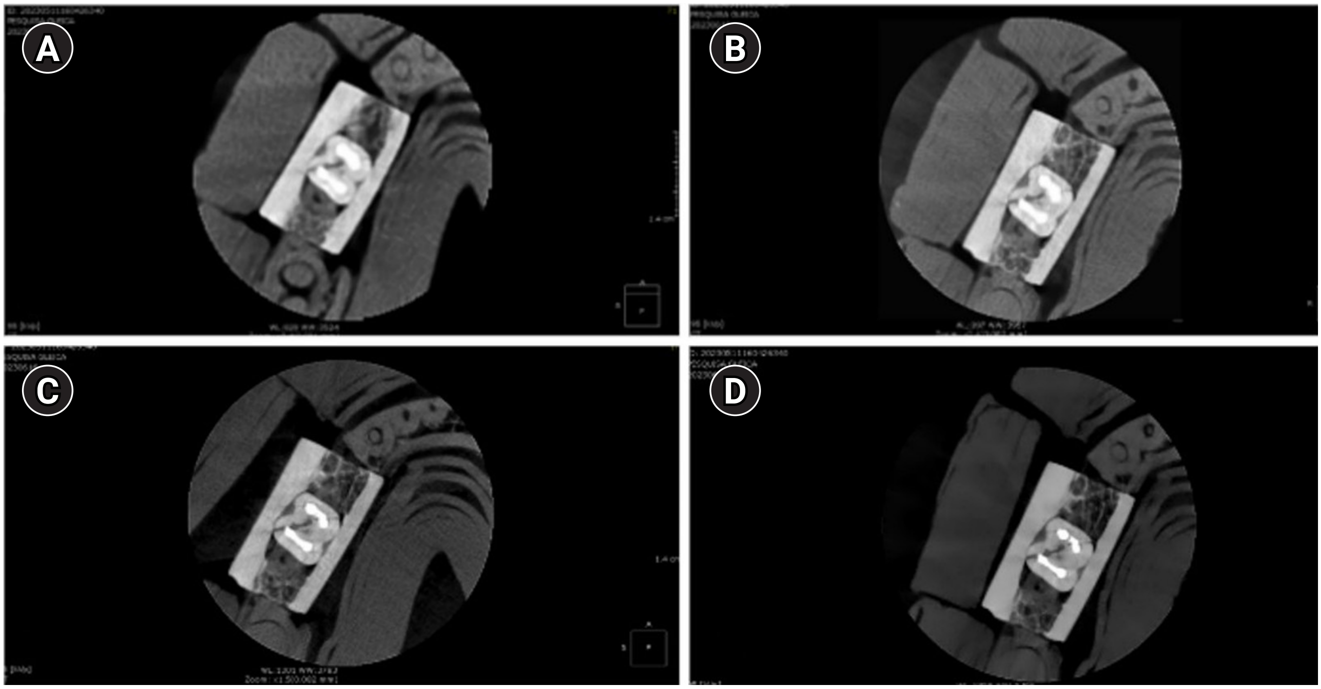

Figure 1. Axial cone-beam computed tomography slices of a sample tooth without post acquired on the four protocols. (A) Low dose resolution, (B) standard resolution, (C) high resolution, and (D) endo resolution.

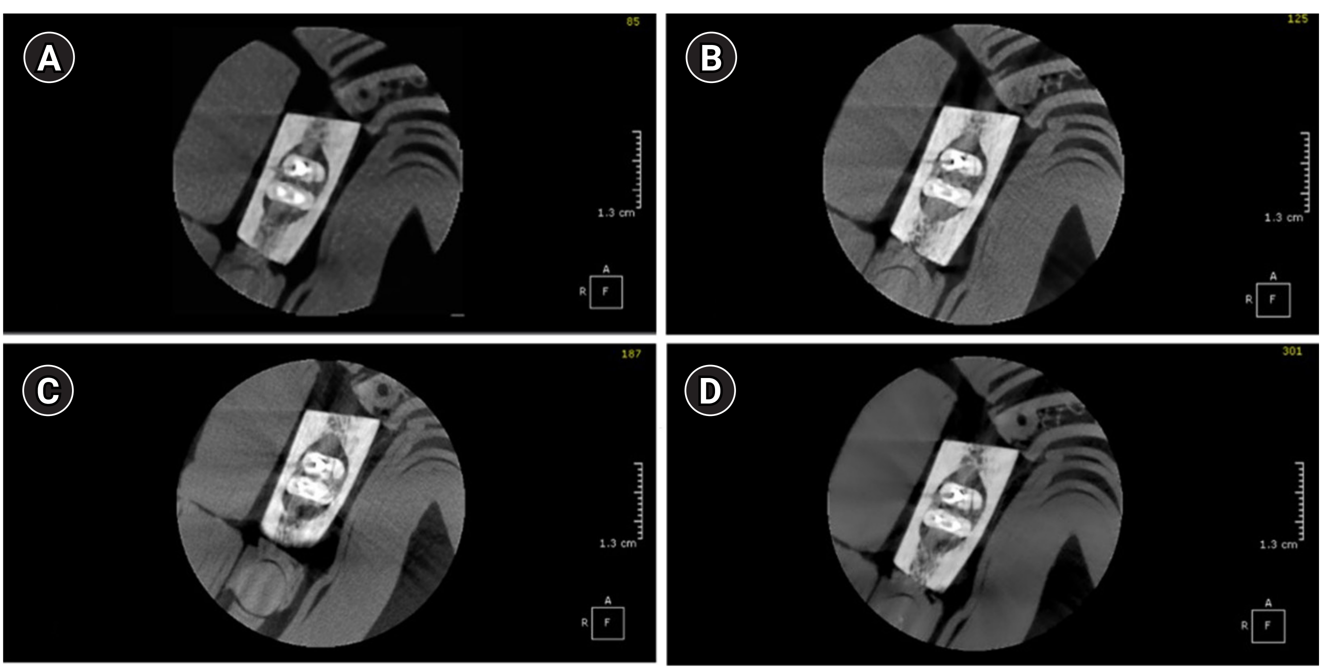

Figure 2. Axial cone-beam computed tomography slices of a sample tooth with post acquired on the four protocols. (A) Low dose resolution, (B) standard resolution, (C) high resolution, and (D) endo resolution.

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ered with wax, though this still represents a simplified approximation of actual clinical conditions.

CBCT image interpretation is inherently operator-dependent and labor-intensive. Thus, variability related to examiner fatigue and intra-observer consistency represents a potential source of error. These human factors, particularly fatigue in less-experienced examiners, remain underexplored in the context of CBCT interpretation and warrant further investigation under real clinical conditions. Additionally, the use of a single CBCT system limits the generalizability of the findings. While all available exposure parameters were tested, the results are specific to that scanner. Still, this choice was deliberate to avoid inter-scanner variability, which could introduce confounding variables.

Another limitation lies in the method used to induce fractures. Although controlled mechanical fractures were necessary to standardize comparisons, they may not fully represent the morphological diversity of naturally occurring root fractures. Clinically, root fractures may vary in location (coronal, middle, or apical third) and often present in early or incomplete stages, which are harder to detect. In contrast, the fractures in this study were complete and oriented in the coronal-apical direction. Additionally, larger and more obvious fracture lines are generally easier to detect [32,41], which may have influenced diagnostic performance. Nevertheless, all evaluations were conducted on the same fracture lines, ensuring internal consistency. Finally, this study did not incorporate clinical signs and symptoms, which are essential in real-life diagnosis and decision-making. This exclusion was intentional to isolate and evaluate the accuracy of CBCT imaging alone in detecting root fractures.

Despite the *ex vivo* design, the findings demonstrate that students can achieve accurate diagnoses, even for challenging cases like molar root fractures, when appropriate acquisition protocols are used. This reinforces the need to incorporate CBCT training early in dental education, covering topics such as digital imaging principles, exam justification, and software manipulation. Given the increasing reliance on CBCT in dental practice, equipping pre-doctoral students with these skills is essential.

CONCLUSIONS

In conclusion, root fracture diagnosis is highly dependent on the CBCT acquisition protocol, with high-resolution protocols recommended for cases involving metallic posts. Examiner expertise significantly affects diagnostic accuracy, particularly when low-resolution protocols are used. These findings highlight the importance of tailored CBCT protocols and early training in improving diagnostic outcomes.

CONFLICT OF INTEREST

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

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AUTHOR CONTRIBUTIONS

Conceptualization, Data curation, Formal analysis, Investigation: Savegnago GDO, Liedke GS. Funding acquisition, Project administration, Resources, Software, Supervision: Liedke GS. Methodology, Validation, Visualization: all authors. Writing - original draft: Savegnago GDO, Liedke GS. Writing - review & editing: all authors. All authors read and approved the final manuscript.

DATA SHARING STATEMENT

The datasets are not publicly available but are available from the corresponding author upon reasonable request.

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Analysis of thermal profiles on tooth structure and insert during one-piece or adapter-coupled ultrasonic insert use: an *in vitro* experimental study

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ABSTRACT

Objectives: This *in vitro* study aimed to evaluate temperature variation on the external surface of mandibular molars and within ultrasonic inserts when using adapter-coupled versus one-piece inserts.
Methods: Twenty-four extracted human mandibular molars were divided into two groups based on the type of ultrasonic insert used: adapter-coupled and one-piece inserts. Temperature on the external surface of each tooth was measured with a thermocouple probe positioned in the furcation area, capturing data continuously. The temperature of the ultrasonic inserts was monitored in real-time using a thermal imaging camera. Measurements were taken in a controlled environment without cooling for over 120 seconds. Statistical analysis was conducted using analysis of variance (ANOVA) and two-way ANOVA with repeated measures to evaluate temperature variations between groups and over time, with significance set at 5%.
Results: In the external tooth surface temperature measurements, no significant differences were observed between the groups during the initial 15 seconds ($p = 0.185$) and 30 seconds ($p = 0.067$). However, significant differences emerged at 60 seconds ($p = 0.025$), 90 seconds ($p = 0.024$), and 120 seconds ($p = 0.020$), with the one-piece insert group demonstrating higher temperatures in the furcation region. Thermal imaging of the inserts revealed a significant difference at all time points ($p < 0.001$), with adapter-coupled inserts showing greater heating.
Conclusions: The use of ultrasonic inserts leads to a gradual rise in temperature on the external tooth surface. One-piece inserts generated higher temperatures on the tooth, while adapter-coupled inserts exhibited greater heating within the insert.

Keywords: Endodontics; Dental instruments; Molar; Temperature; Thermal conductivity; Ultrasonics

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INTRODUCTION

Ultrasonic technology offers a wide range of applications in endodontics, making it an invaluable tool for enhancing root canal treatment [1], retreatment [2,3], and endodontic surgery [4,5]. Its uses include refining access to root canals [6,7], locating hidden canals [8,9], and effectively removing pulp calcifications and nodules that may otherwise hinder treatment [10,11]. Furthermore, ultrasonics assists in the removal of fractured instruments [12,13] and root canal posts [14,15] and can prepare areas that traditional instruments struggle to reach, such as isthmuses and flattened canal spaces, thus improving overall cleaning efficacy [16,17]. Ultrasonics is also frequently employed to activate irrigating solutions, increasing their penetration and effectiveness [18,19], and is used in obturation procedures for cutting and condensing gutta-percha [20,21].

Ultrasonics operates by converting electrical energy into high-frequency mechanical vibrations through an ultrasonic insert, a process that can generate heat as vibrational energy dissipates within surrounding tissues and fluids [22]. This heat buildup, if excessive or prolonged, may pose a risk to periodontal structures. When the ultrasonic insert contacts dentin, additional frictional forces can generate even more heat within the tooth structure [23–27]. Excessive heating, if sufficiently intense and/or prolonged, may damage the periodontal ligament and alveolar bone [28,29].

In many of these procedures, continuous cooling is often avoided to maintain clear visualization of the operative field and ensure procedural accuracy. However, without cooling, significant temperature increases can occur in both the tooth structure and surrounding tissues, potentially reaching levels that pose risks to periodontal health [29]. The degree of heat generation varies based on several factors, including the type of ultrasonic insert, power settings, and duration of activation [25]. Despite these known risks, there is a notable lack of studies that quantify the extent of temperature rise in procedures without continuous cooling. A clearer understanding of these thermal effects is essential to establish safer protocols and refine guidelines for procedures where cooling is limited, ultimately protecting patient outcomes and periodontal integrity.

Therefore, the aim of this *in vitro* study was to evaluate temperature variation on the external surface of mandibular molars when using adapter-coupled inserts and one-piece inserts, both operated without cooling for 120 seconds. Additionally, temperature variation within the ultrasonic insert itself during use was assessed. The null hypothesis tested posited that no significant difference in temperature variation would be observed between the different types of inserts.

METHODS

Sample calculation

Sample size calculation was conducted using the program G*Power v3.1 for Mac (Heinrich Heine University of Düsseldorf, Düsseldorf, Germany), based on analysis of variance (ANOVA) with repeated measures. An effect size of 1.78, an alpha error of 0.05, and a power of 95% were set for the calculation. Results indicated that 12 samples per group would be sufficient to detect significant differences.

Sample selection and specimen preparation

This study was approved by the Institutional Research Ethics Committee of Universidade Positivo (CAAE 76141723.6.0000.0093).

Twenty-four extracted human mandibular molars with two roots were selected. The teeth were cleaned, and the crown was opened with round burs until the pulp chamber floor was fully exposed. Radiographs were taken with a digital sensor (Snapshot; Instrumentarium Dental, Tuusula, Finland) using an exposure time of 0.3 seconds and a focal length of 30 cm. The thickness of the furcation wall was measured in millimeters on the radiographs, with all measurements performed by a single operator.

The teeth were paired to create 12 pairs with similar furcation thicknesses. One tooth from each pair was randomly assigned to either the adapter-coupled or one-piece insert group (Figure 1).

- Adapter-coupled group: adapter + spherical diamond insert (Dental Trinks, São Paulo, Brazil) (n = 12)
- One-piece insert group: spherical diamond insert (Dental Trinks) (n = 12)

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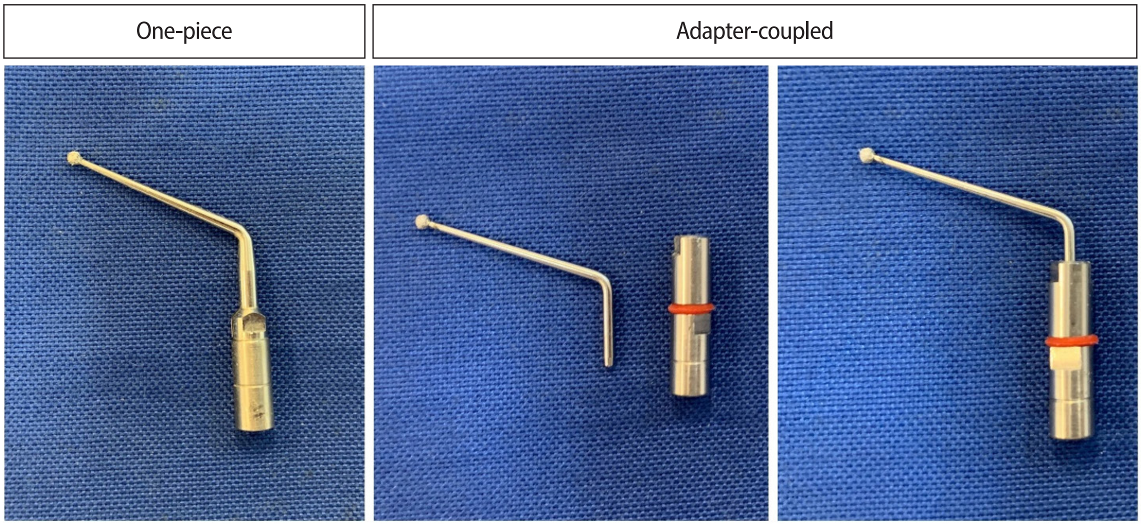

Figure 1. Ultrasonic inserts used in the study. Spherical diamond insert in one-piece insert and adapter + spherical diamond insert in adapter-coupled inserts.

A total of 24 inserts from the same manufacturer were used, 12 from each model, with a single insert designated for each tooth. The teeth were stored in distilled water at 37°C until the time of the experiment.

Use of ultrasonic inserts

The experiment was conducted in a room with controlled temperature and humidity. Each specimen was fixed in floral foam, immersed in water, and maintained at 35°C in a bottle warmer. A thermocouple tip (type K universal MTK-01; Minipa do Brasil, São Paulo, Brazil) connected to an Arduino UNO R3 data acquisition device (Arduino, Ivrea, Italy) was positioned between the floral foam and the furcation area of the tooth. This setup transmitted the temperature-time profile to a computer, enabling continuous recording of temperature changes on the root's outer surface every second for 120 seconds.

A thermal imaging camera (Ti9; Fluke, Everett, WA, USA) was used to record the temperature variation in the ultrasonic insert during use. The camera was mounted on a support at a distance of 50 cm from the experimental setup.

Ultrasonic activation was performed using an ultrasonic unit (P5 XS Bled Newtron; Satelec Acteon, Mérignac, France) set at a power level of 10, corresponding to 50% of the device's maximum power output. Each insert was moved in a linear motion within the furcation region of the tooth, with a 3-mm forward and backward amplitude, maintained throughout the experiment. To standardize the ultrasonic action, the transducer was attached to a device that enabled precise 3 mm horizontal movement on each tooth.

This procedure was performed by a single trained operator with 20 years of experience in endodontics. The temperature variation of the tooth surface and ultrasonic insert was evaluated at 15, 30, 60, 90, and 120-second intervals for the two groups.

Statistical analysis

Data were analyzed using Jamovi software, ver. 1.6 (The Jamovi Project, 2021). Normality was assessed with the Shapiro-Wilk test, confirming a normal distribution. Temperature variation was evaluated using ANOVA, followed by the Tukey test for multiple comparisons. A two-factor ANOVA with repeated measures was conducted to analyze the effect of time within each group. The significance level was set at 5%.

RESULTS

On the external tooth surface, no statistically significant difference between the groups was observed at 15 seconds ($p = 0.185$) and 30 seconds ($p = 0.067$). However, significant differences emerged at 60 seconds (p = 0.025), 90 seconds (p = 0.024), and 120 seconds (p = 0.020), with one-piece inserts recording higher temperatures across all intervals. At 120 seconds, the average temperature for one-piece inserts reached 55.6°C ± 9.06°C, while adapter-coupled inserts averaged 48.3°C ± 4.50°C (Table 1).

Regarding the temperature of the ultrasonic insert itself, statistically significant differences were observed across all evaluated intervals ($p < 0.001$), with adapter-coupled inserts exhibiting higher temperatures throughout. At 120 seconds, the average temperature reached 58.5°C ± 7.99°C in the adapter-coupled group, compared to 46.4°C ± 4.74°C in the one-piece group. Furthermore, within each group, a consistent temperature increase was observed with prolonged activation time ($p < 0.001$).

Thermal images captured during the experiment showed that, for adapter-coupled inserts, the highest temperatures were concentrated at the junction between the adapter and the insert. In contrast, for one-piece inserts, the greatest heating occurred at the point of contact between the insert and the tooth. Figure 2 illustrates these differences, highlighting the areas of maximum temperature for each insert type.

DISCUSSION

The aim of this study was to assess temperature variation on the external surface of mandibular molars when using adapter-coupled inserts compared to one-piece inserts over a 120-second period. The null hypothesis was partially rejected, as significant differences in heating were found between the two insert types. Notably,

Table 1. Temperature recorded on the tooth's external surface and the ultrasonic insert at 15, 30, 60, 90, and 120 second intervals in both the adapter-coupled and one-piece insert groups

Temperature variation	Inserts	Time (sec)				
		15	30	60	90	120
Tooth	Adapter-coupled	$38.6 \pm 1.91^{a,A}$	$41.6 \pm 3.13^{a,B}$	$44.6 \pm 4.26^{b,C}$	$46.5 \pm 4.37^{b,D}$	$48.3 \pm 4.50^{b,D}$
	One-piece	$40.3 \pm 3.88^{a,A}$	$45.5 \pm 6.23^{a,B}$	$50.0 \pm 6.53^{a,C}$	$52.7 \pm 7.73^{a,D}$	$55.6 \pm 9.06^{a,E}$
Insert	Adapter-coupled	$44.8 \pm 1.96^{a,A}$	$47.5 \pm 2.39^{a,A}$	$52.8 \pm 5.37^{a,B}$	$56.1 \pm 6.91^{a,C}$	$58.5 \pm 7.99^{a,D}$
	One-piece	$34.6 \pm 3.73^{b,A}$	$36.3 \pm 5.68^{b,A}$	$42.7 \pm 2.90^{b,B}$	$45.1 \pm 4.23^{b,C}$	$46.4 \pm 4.74^{b,C}$

Values are presented as mean ± standard deviation.
Different lowercase superscript letters indicate statistical differences within the same column for tooth and insert temperature variables (Tukey test, $p < 0.05$). Different uppercase superscript letters indicate statistical differences across the same row (two-way analysis of variance with repeated measures, $p < 0.05$).

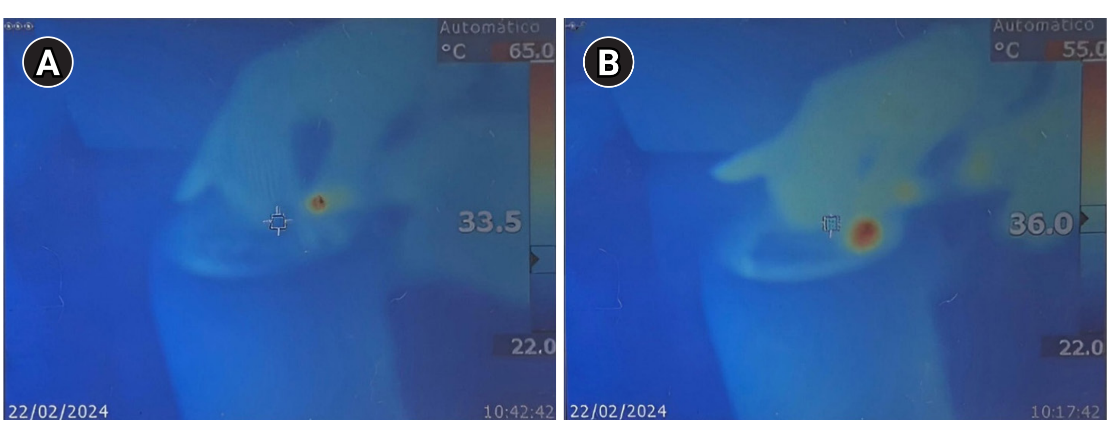

Figure 2. Thermal images captured during the experiment. (A) Adapter-coupled inserts. The highest temperatures were concentrated at the junction between the adapter and the insert. (B) One-piece inserts. The greatest heating occurred at the point of contact between the insert and the tooth.

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after 60 seconds of continuous activation, the tooth temperature showed a significant increase in the one-piece insert group compared to the adapter-coupled group (Table 1).

A progressive temperature increase was observed with prolonged activation time, a finding of clinical relevance as these values exceeded critical thresholds for maintaining the viability of dental tissues. Temperatures exceeding 43°C—recorded as early as 30 seconds after activation—are particularly concerning, as they have been associated with periodontal ligament necrosis [30], dental ankylosis [31], and bone resorption [28]. The periodontal ligament, a delicate connective tissue with limited regenerative capacity, is especially vulnerable to thermal damage. Unlike mineralized tissues, which may tolerate brief periods of elevated temperature, the periodontal ligament is more susceptible due to its rich vascular and cellular components. Sustained heating can compromise its blood supply and structural integrity, potentially leading to irreversible injury [30,31]. These findings underscore the risk posed to periodontal and periapical tissues during extended ultrasonic activation and highlight the critical importance of effective cooling strategies. In the absence of adequate cooling, the likelihood of thermal injury to the periodontal ligament becomes clinically relevant. These results are consistent with previous studies that also demonstrated cumulative temperature rises with ultrasonic use [24–27].

To mitigate the risk of thermal damage to tissues adjacent to the tooth during ultrasonic use, continuous irrigation is widely recommended [22–26,32]. However, in various endodontic procedures—such as refining root canal access, locating canals, removing pulp calcifications and nodules, cutting and condensing gutta-percha, and performing endodontic retreatments—continuous irrigation is impractical, as it can obscure visualization and, in some cases, impede the procedure itself. To counteract potential thermal risks, periodic ultrasonic activation is recommended, with interruptions every 30 seconds to allow for irrigation and cooling [10,33].

In this study, temperatures exceeding 43°C were recorded after just 30 seconds of continuous ultrasonic use. Based on these findings, it is recommended to take breaks for irrigation and cooling every 15 seconds, as this interval provides sufficient working time while reducing the risk of reaching harmful temperature levels. The results also highlight considerable heating of the ultrasonic inserts themselves. Thermal imaging showed that in the adapter group, peak temperatures occurred at the junction between the adapter and the insert, while in the one-piece group, the highest temperatures were observed at the contact point between the insert and the tooth.

Although cutting effectiveness was not the primary focus of this study, an observed difference between inserts with adapters and one-piece inserts raises interesting considerations. While adapters offer cost benefits and enable tip interchangeability, they may dampen the vibration of the inserts, particularly at lower power settings [34]. In this study, the reduced heating of teeth observed when using inserts with adapters suggests that some vibrational energy may dissipate at the adapter-insert junction, potentially impacting cutting efficiency. However, it is important to note that these observations are qualitative rather than quantitatively substantiated. Future studies with precise quantitative analyses are necessary to confirm this effect and evaluate its clinical significance, particularly for cases requiring high cutting precision. Furthermore, research is needed to assess how cutting effectiveness, the amount of material removed, and the remaining dentin thickness influence the heat generated and transmitted to the periodontal ligament and alveolar bone. This insight may assist endodontists in selecting the most appropriate insert, especially in cases requiring high cutting precision.

In this study, a stainless steel, spherical diamond insert was selected due to its versatility, making it suitable for a broad range of clinical applications, including canal localization, removal of coronal obstructions, restorative materials, calcifications, and both temporary and permanent cements. Nonetheless, ultrasonic inserts differ considerably in design and material composition, factors that may significantly influence their thermal behavior during clinical use. Therefore, further studies are warranted to explore the thermal profiles of inserts with varying geometries and materials, aiming to generate evidence-based recommendations for optimal insert selection according to specific clinical scenarios.

Although this study provides valuable data on the heat generated during ultrasonic use in endodontics, several limitations should be noted. First, the *in vitro* nature of the study cannot fully replicate the complex dynamics present in the clinical environment, where variables such as tissue type and individual anatomical differences may influence temperature dissipation. Additionally, while we observed differences in heat generation between one-piece and adapter-coupled inserts, the exact impact of these temperature variations on adjacent tissues, particularly over extended periods, remains unclear. Future studies should explore the effects of sustained ultrasonic use on periodontal ligament and alveolar bone cells to determine the clinical significance of elevated temperatures. Furthermore, it would be beneficial to investigate how temperature varies across different power settings, insert designs, and irrigation techniques. Finally, expanding this research to include a variety of ultrasonic insert designs and coupling systems could offer a more comprehensive understanding of safety and efficacy, ultimately guiding clinicians in selecting the most appropriate tools for specific endodontic procedures.

This study highlights the importance of managing heat generation during the use of ultrasonic inserts in endodontics. While efficient cutting is crucial for procedures such as root canal access refinement and calcification removal, our findings confirm that ultrasonic activation, particularly with one-piece inserts, can rapidly increase temperatures to levels that may jeopardize periodontal and surrounding tissue health. Clinically, this underscores the need for incorporating cooling pauses and, when feasible, intermittent irrigation to mitigate thermal buildup. By balancing effective cutting with thermal management strategies, clinicians can perform ultrasonic procedures with greater safety, reducing the risk of thermal injury while maintaining the efficiency needed for precise endodontic work.

CONCLUSIONS

The use of spherical ultrasonic inserts leads to a gradual rise in temperature on the external tooth surface. One-piece inserts generated higher temperatures on the tooth, while adapter-coupled inserts exhibited greater heating within a spherical insert.

CONFLICT OF INTEREST

Emmanuel João Nogueira Leal da Silva is the Associate Editor of *Restorative Dentistry and Endodontics* and was not involved in the review process of this article. The authors declare no other conflicts of interest.

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AUTHOR CONTRIBUTIONS

Conceptualization: Crozeta BM, Marques-da-Silva B, Tomazinho FSF, Diógenes AN. Investigation: Crozeta BM, Marques-da-Silva B. Methodology: Brotto GL, Tomazinho FSF. Supervision: Tomazinho FSF, Diógenes AN. Validation: Diógenes AN. Writing - original draft: Brotto GL, Tomazinho FSF. Writing - review & editing: Crozeta BM, Silva EJNL. All authors read and approved the final manuscript.

DATA SHARING STATEMENT

The data supporting this study's findings are available from the corresponding author upon reasonable request.

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Calcium silicate-based sealers remnants in isthmuses of mesial roots of mandibular molars: an *in vitro* evaluation

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ABSTRACT

Objectives: Endodontic retreatment aims to address treatment failure through the removal of root canal filling materials. This *in vitro* study evaluated the presence of filling material remnants in the mesial root canals, specifically focusing on the isthmuses, of mandibular molars after retreatment.
Methods: One hundred extracted mandibular molar mesial roots with isthmuses were prepared with an R25 file, obturated with one of five calcium silicate-based sealers (BioRoot RCS [Septodont], MTApex [Ultradent Products Inc.], EndoSequence BC Sealer HiFlow [Brasseler USA], Bio-C Sealer [Angelus]) or an epoxy resin-based sealer (AH Plus Jet [Dentsply Maillefer]), all stained with rhodamine B, and stored at 37ºC for 30 days to allow for setting. Retreatment was subsequently performed using R40 and XP-endo Finisher R instruments (FKG Dentaire) with 2.5% sodium hypochlorite irrigation. The presence of remaining filling material was then assessed using confocal microscopy, and setting times were tested per ISO 6876:2012.
Results: AH Plus Jet showed the most remnants at 2 mm and the longest retreatment time. Calcium silicate-based sealers exhibited prolonged setting times under dry conditions, with EndoSequence BC Sealer HiFlow showing a particularly extended setting period.
Conclusions: Despite retreatment, residues remained in all canals and isthmus regions, particularly Bio-C Sealer and AH Plus Jet in apical areas, emphasizing the difficulty of complete removal and the persistence of filling material.

Keywords: Confocal microscopy; Endodontics; Retreatment; Root canal filling materials; Root canal obturation

INTRODUCTION

Endodontic treatment failure can arise from the persistence of residual bacteria following chemical-mechanical preparation, sustained by fluid percolation from the periapex, leading to intra- and extraradicular

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infections and subsequent periradicular lesions [1]. These microorganisms can resist to the endodontic treatment and remain in regions of anatomical complexities of root canals such as isthmuses, C-shaped canals, lateral canals, ramifications, and dentinal tubules [2,3].

Endodontic sealers, depending on their material characteristic, can influence the patency regaining, tooth retreatability, retreatment time, and the presence of obturation material remnants within the root canals; several previous studies evaluated the effectiveness of removal investigating different types of sealers [4]. Among these endodontic materials, the most evaluated were those based on epoxy resin, calcium silicate-based, and zinc oxide and eugenol-based, but there are some controversial results between these studies. The comparison between the removal of epoxy resin and calcium silicate-based sealers showed similar results between these materials [5–7], while other studies mentioned a greater amount of residue for epoxy resin-based sealers [8,9], whereas there are reports of greater amounts for calcium silicate-based sealers [10]. Besides, there are reports that the calcium silicate-based sealers require a long time for retreatment [8]. There is evidence that the composition of the material is a variable that interferes with root canal retreatment, considering these discrepancies reported.

Complementary endodontic instruments can potentially aid during retreatment in the removal of obturation material. XP-endo Finisher R rotary file (FKG Dentaire, La Chaux-de-Fonds, Switzerland) was designed to be used in regions of anatomical complexities such as root canal isthmuses along with instrumentation during root canal retreatment [11,12]; besides, there are reports of its use in oval root canals [13]. Previous reports also associated the use of the XP-endo Finisher in retreated root canals filled with calcium silicate-based sealers as an improvement for the obturation material removal [5,9]. Therefore, the investigation regarding the use of an additional cleaning instrument is crucial, especially considering anatomical irregularities [4].

The correlation between filling material removal during retreatment and sealer type warrants investigation. Sealers vary in composition, with some requiring mixing to start setting immediately, while "ready-to-use" sealers rely on assumed moisture contact within root canal dentin to initiate setting and hydration [14].

The hydration process of 'ready-to-use' sealers in root canals is still not well elucidated, and whether the total setting reaction takes place, because these materials are moisture-dependent. Thus, it is possible that in areas of anatomical complexities, such as isthmuses, dentin moisture is not sufficient for the complete setting of 'ready-to-use' sealers, considering the high volume of material in these regions [15]. A delayed setting reaction in sealers is thought to increase solubility and the risk of failure. However, no studies have addressed the effectiveness of retreatment in root canal isthmus regions focusing on pre-mixed calcium silicate-based materials, particularly in narrow areas like those in maxillary premolars and between the mesiolingual and mesiobuccal canals of mandibular molars [16,17]. In isthmuses, these two forms of calcium silicate-based sealers (powder/liquid and 'ready-to-use') behavior regarding their hydration reactions and setting deserve investigation.

Based on the potential influence of local humidity on the setting reaction of calcium silicate-based sealers and their subsequent removal, particularly in areas of anatomical complexity such as isthmuses, we hypothesized that the effectiveness of retreatment would be affected. Therefore, the aim of this study was to evaluate the remaining filling material in canals with isthmuses of mesial roots of mandibular molars using five different sealers. Additionally, to evaluate the time of retreatability and the setting time of the investigated sealers.

METHODS

Ethical approval statement

The research project was submitted and approved by the ethics committees of the University of São Paulo and the University of Campinas (CEP 5479358/CEP 5691992).

Sample size estimation

The sample size for human teeth was determined using G*Power v3.1 (Heinrich-Heine-Universität Düsseldorf, Germany), based on prior studies [13,15]. For analysis of variance (ANOVA) comparison of four groups, a standard deviation of 0.26, a minimum detectable difference

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of 0.15, a test power of 0.80, and an alpha of 0.05 indicated 20 teeth per group. Similarly, the sample size for sealer setting time analysis was calculated using prior studies [18,19] and a pilot study, with an alpha of 0.05, power of 0.80, and an effect size of 2.45, resulting in six samples per group.

Selection and preparation of teeth

The study included 100 human mandibular molars (first and second) from donors aged 30 to 60 years, stored in 0.9% saline solution. Teeth met the inclusion criteria of no previous endodontic treatment, extensive caries, or incomplete root formation. Isthmuses at 2, 4, and 6 mm from the apex were confirmed, and only Vertucci types II, III, V, VI, and VII canal configurations were selected. Microcomputed tomography (SkyScan 1174; Bruker, Kontich, Belgium) was used to assess canal anatomy and isthmus presence, ensuring consistent mesial canal patterns.

Initially, the coronal access was performed. Afterward, the teeth foramina were sealed with utility wax and inserted into a silicone mold, then filled with colorless acrylic resin up to the enamel-cement junction. After resin hardening, the block with the tooth was removed from the silicone mold. Markings were made on the blocks corresponding to 2, 4, and 6 mm from the apex, and then, cross-sectional cuts were made through these areas using a 0.3-mm-thick diamond disc coupled to an Isomet cutter (Buehler, Lake Bluff, IL, USA), resulting in 2-mm-thick sections. The sections were placed into an ultrasonic bath with distilled water for 7 minutes to remove the debris originating from the cut. The sections were again inserted into the silicone mold and prepared for canal instrumentation up to foraminal patency. The instrumentation protocol started with initial exploration with a #10 C-pilot file (VDW GmbH, Munich, Germany) using exploration movements (introduction of the file with light pressure and 1/4 rotation turn clockwise and counter-clockwise) to check the existence of foraminal patency. In cases where patency was not established after this exploration, reaming movements and light apical-only instrumentation movements were performed.

Then, driven by an electric motor (VDW GmbH), Reciproc Blue R25 system (VDW GmbH) instrumentation was performed with reciprocating motion using the actual length of the tooth as the working length. For irrigation, each tooth was irrigated with 5-mL sodium hypochlorite 2.5% (Asfer Indústria Química Ltda, São Caetano do Sul, Brazil) using a 30-guage Navitip needle (Ultradent Products Inc., South Jordan, UT, USA) inserted at 2 mm short of the working length and remaining in the canals for 30 seconds. A final irrigation protocol was performed using 2-mL 17% ethylenediaminetetraacetic acid (EDTA; Maquira, Maringá, Brazil) using a 30-G Navitip needle. Subsequently, solution activation was performed for 20 seconds with an E1-Irrisonic 20.01 ultrasonic insert (Helse Dental Technology, Santa Rosa de Viterbo, Brazil) at 2 mm short of the working length. This procedure was repeated in triplicate, resulting in a total of 6 mL of 17% EDTA and 60 seconds of activation. Finally, root canals were irrigated with 6 mL of saline solution and dried using 35.04 paper points (Dentsply Maillefer, Ballaigues, Switzerland).

To ensure consistent levels of cleanliness among all root canals and achieve sample standardization, a low-vacuum scanning electron microscope (SEM; PSEM eXpress, Aspex Corp., Delmont, PA, USA) was performed on all teeth prior to obturation without any sample preparation. Subsequently, the teeth underwent randomization and were allocated into five groups (n = 20) based on the experimental design, according to the materials detailed in Table 1.

The experimental groups underwent the root canal obturation process using the single-cone technique. Initially, the sealers were introduced into the canals using a size 30 Lentulo instrument (Dentsply Maillefer), positioned 2 mm short of the apex. Subsequently, gutta-percha cones 25.08 (VDW GmbH) were inserted 1 mm short of the apex along with the respective endodontic sealer. Periapical radiographs were taken simultaneously to assess the quality of obturation.

According to a previous method [15] for confocal microscopy analysis, the sealers were mixed with rhodamine B 0.1% dye before their insertion into the root canals. After completing the obturation, the teeth were placed in containers with moistened gauze and stored in a humid oven at 37°C for 1 month. In sequence, samples underwent a canal retreatment procedure. For this procedure, all teeth were retreated using R40 (VDW GmbH) and instrumentation supplemented

Table 1. Composition and batch number of the root canal sealers used in the analysis

Material	Manufacturer	Batch	Composition
BioRoot RCS	Septodont (Saint-Maur-des-Fossés, France)	Powder B23970	Tricalcium silicate, zirconium oxide, and povidone
		Liquid B23099	Aqueous solution of calcium chloride and polycarboxylate
MTApex Sealer	Ultradent Products Inc. (South Jordan, UT, USA)	Powder 2019102403	Tricalcium silicate, tricalcium aluminate, and tantalum oxide
		Liquid 2020011401	Water-based gel
EndoSequence BC Sealer HiFlow	Brasseler USA (Savannah, GA, USA)	2001SPWF	Tricalcium silicate, dicalcium silicate, calcium hydroxide, zirconium oxide, and fillers
Bio-C Sealer	Angelus (Londrina, Brazil)	60406	Calcium silicate, calcium aluminate, calcium oxide, zirconium oxide, iron oxide, silicon dioxide and polyethylene glycol
AH Plus Jet	Dentsply Maillefer (Ballaigues, Switzerland)	2204000437	Epoxide paste: bisphenol-A epoxy resin, bisphenol-F epoxy resin, calcium tungstate, zirconium oxide, aerosol, and pigment
			Amine paste: 1-adamantane amine N, N′-dibenzyl-5-oxa-nonandiamine-1, 9 TCD-Diamine, calcium tungstate, zirconium oxide, aerosol, and silicone oil

with XP-endo Finisher R, with 2.5% sodium hypochlorite irrigation using a syringe with a 30-G Navitip needle until reestablishing apical patency.

All chemical-mechanical preparation, obturation, and retreatment procedures were performed by the same previously trained professional (DSBA) with the assistance of an operative microscope.

Confocal microscope analysis

Images of the 2, 4, and 6 mm of the apex were obtained through confocal microscopy (Confocal Microscope Leica TCS SPE; Leica Microsystems GmbH, Wetzlar, Germany; 50× magnification) with the following parameters: objective lens, N Plan 5.0 × 0.12 DRY; laser, 532 nm (visible range), emission bandwidth, 546 to 740 nm; and image resolution, 512 × 512.

The images were analyzed using the Image Tool 3.0 software (The University of Texas Health Science Center at San Antonio, San Antonio, TX, USA), and the calculation of both the total area of remaining endodontic sealers and the sealer in the isthmuses was performed after retreatment and expressed in percentage according to the following equation :

$$Remnant\ material\left(\%\right) = \frac{Area\ of\ remnant\ material\ \times\ 100}{Total\ area\ of\ canal\ or\ isthmus}$$

Retreatment time analysis

The retreatment time during endodontic retreatment procedures was evaluated by recording time (in seconds), with a digital stopwatch. Time measurement started from the moment the instrument encountered the root canal, and the final time for retreatment was recorded when apical patency was reestablished.

Setting time analysis (moist and dry conditions)

The setting time test was prepared using moist and dry methods, according to the ISO 6876:2012 standards. The moist method used previously manufactured round plaster molds (Durone-IV; Dentsply Maillefer) measuring 10 × 1 mm, which were kept immersed in distilled water for 24 hours at 37°C and filled with endodontic sealers ($n = 6$). For the dry method, the tested endodontic sealers ($n = 6$) were placed inside stainless steel rings (10 × 2 mm), under a glass plate, and stored at 37°C relative humidity.

The setting of the materials was evaluated by placing a 100-G Gilmore needle with a 2-mm tip vertically into the sample surface initially to determine the initial setting time every 30 minutes and at shorter intervals as the setting reaction progressed. The initial setting time was determined from the beginning of material manipulation until the needle indentation was no longer observed on the material's surface.

Statistical analysis

GraphPad Prism 9 software (GraphPad Software, San Diego, CA, USA) was used for statistical analysis. Normal distributions were assessed using Shapiro-Wilk test.

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Mixed ANOVA of the within-and-between effects of the subjects used a *post hoc* analysis with the Tukey test for multiple comparisons. All statistical tests were performed at a significance level of 5% ($\alpha = 0.05$).

RESULTS

The analysis of the remnant endodontic sealers after the retreatment for both the canals and isthmuses of the mesial roots of mandibular molars, in the regions of 6, 4, and 2 mm, is shown in Figures 1 and 2, respectively.

For the analysis of the remnant filling material inside the canals, in the 6-mm section, there was no statistically significant difference between the remnant filling material in any of the endodontic sealers ($p > 0.05$). In the 4-mm section, the Bio-C Sealer (Angelus, Londrina, Brazil) presented an average of remnant material inside the canals (21.3% ± 15.1%) greater than all other sealers tested ($p < 0.05$). At the 2-mm section, AH Plus Jet exhibited the highest mean percentage of remnant in the canals (12.4% ± 8.4%) when compared to other materials ($p < 0.05$).

For the remnant filling material inside the isthmuses, in the 6-mm section, there was also no statistically significant difference between the remaining filling material in the isthmuses between the endodontic sealers evaluated ($p > 0.05$). In the 4-mm section, AH Plus Jet sealer showed a statistically significant difference in relation to the percentage of remnant filling material (68.0% ± 26.5) when compared to the BioRoot RCS (Septodont, Saint-Maur-des-Fossés, France) and MTApex sealers (Ultradent Products Inc.) ($p < 0.05$). Besides, in the region of 2 mm, AH Plus Jet also presented the highest percentage of remnant filling material (80.4% ± 19.4) than the BioRoot RCS and MTApex materials ($p < 0.05$). Representative confocal microscopy images of the evaluated samples after the retreatment procedures are shown in Figure 3, indicating a higher degree of remnants within the isthmuses.

The time elapsed for the endodontic retreatments until the reestablishment of the working length patency was obtained is indicated in Table 2. Patency was reestablished in all specimens. AH Plus Jet demanded the longest mean retreatment time compared to all other materials ($p < 0.05$). There was no statistically significant difference between BioRoot RCS, MTApex, and EndoSequence BC Sealer HiFlow sealers (Brasseler USA, Savannah, GA, USA) ($p > 0.05$), and Bio-C Sealer required the

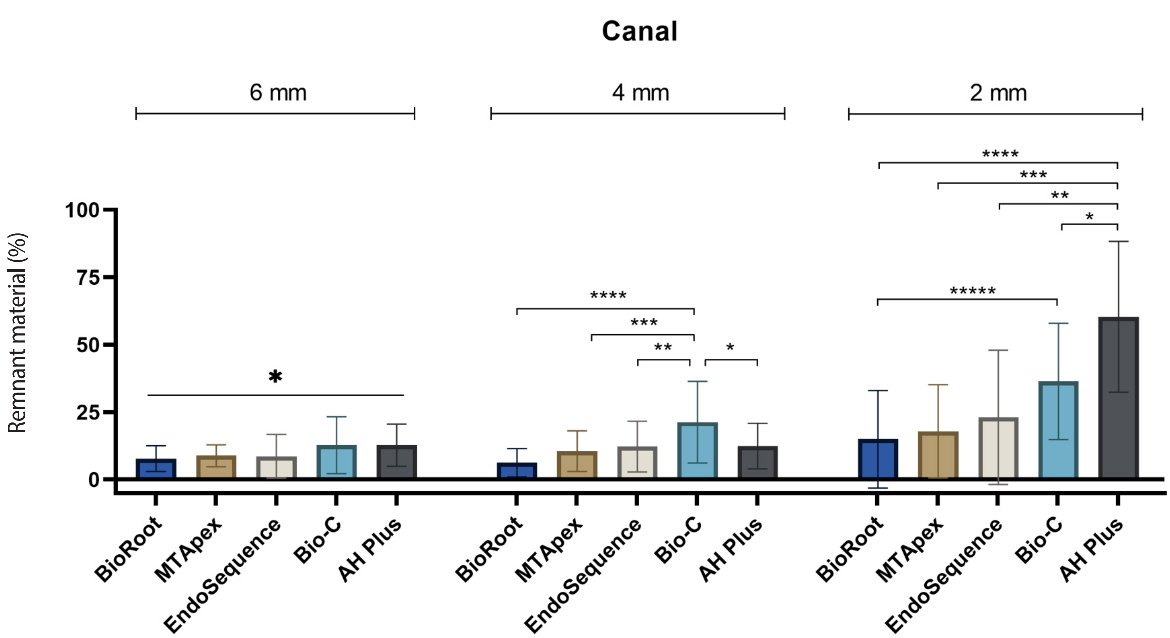

Figure 1. Representation of the mean and standard deviation values in percentage of remnant filling material in canals at the 6-, 4- and 2-mm levels. Bars linking different materials with asterisks indicate statistically significant differences (*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$). Manufacturer information for each material is provided in Table 1.

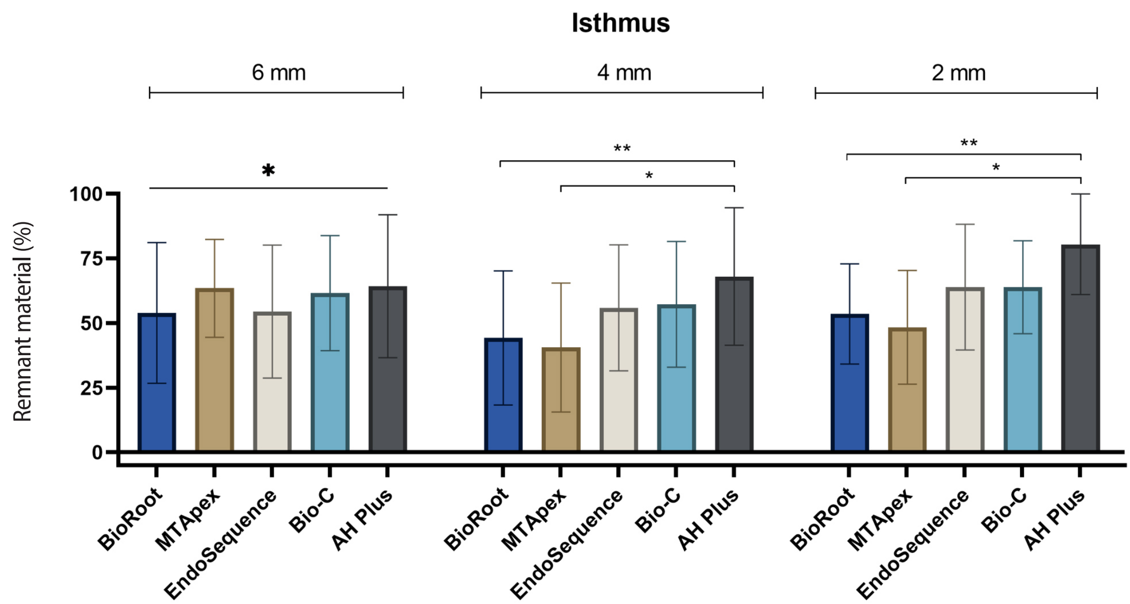

Figure 2. Representation of the mean and standard deviation values in percentage of remnant filling material in isthmuses at the 6-, 4- and 2-mm levels. Bars linking different materials with asterisks indicate statistically significant differences (*$p < 0.05$, **$p < 0.01$). Manufacturer information for each material is provided in Table 1.

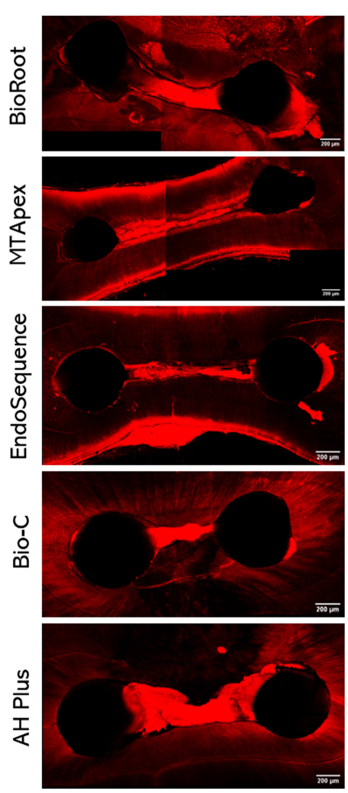

Figure 3. Confocal microscopy representative images of the canal and isthmuses at 4 mm after endodontic retreatment procedures with the tested materials. Manufacturer information for each material is provided in Table 1.

Table 2. The retreatment time for all tested materials

Tested material	Retreatment time (sec)
BioRoot RCS	167.3 ± 46.01^{B}
MTApex	161.5 ± 36.46^{BC}
EndoSequence BC Sealer HiFlow	170.2 ± 25.88^{B}
Bio-C Sealer	130.4 ± 11.37^{C}
AH Plus Jet	225.2 ± 33.57^{A}

Values are presented as mean ± standard deviation.
Different uppercase letters indicate statistically significant differences between materials ($p < 0.05$).
Manufacturer information for each material is provided in Table 1.

lowest retreatment time.

Table 3 shows the mean and standard deviation values for the setting times for materials' setting time in moist and dry methods. Regardless of the method of analysis, EndoSequence BC Sealer HiFlow had the highest average setting time among the evaluated calcium silicate-based materials ($p < 0.05$). In the moist method, all calcium silicate-based sealers obtained a lower mean setting time when compared with the dry method ($p < 0.05$). AH Plus Jet was not influenced by the experimental setting time method ($p > 0.05$).

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Table 3. Representation of the values of setting time of the tested materials

Tested material	Setting time (min) under each condition	
	Moist	Dry
BioRoot RCS	251.8 ± 8.98^{ABCa}	615.8 ± 3.07^{Ab}
MTApex	226.3 ± 40.2^{Ba}	512.9 ± 18.78^{Bb}
EndoSequence BC Sealer HiFlow	351.6 ± 45.19^{Ca}	2751 ± 48.67^{Cb}
Bio-C Sealer	65.77 ± 4.71^{Da}	251.0 ± 52.77^{Db}
AH Plus Jet	615.3 ± 10.29^{Ea}	675.6 ± 138.7^{Aa}

Values are presented as mean ± standard deviation.
Different uppercase letters indicate statistically significant differences between materials ($p < 0.05$). Different lowercase letters indicate statistically significant differences the method for each material ($p < 0.05$).
Manufacturer information for each material is provided in Table 1.

DISCUSSION

The aim of the study was to evaluate the remaining filling material in canals with isthmuses of mesial roots of mandibular molars. This was achieved by preparing mesial roots of mandibular molars with confirmed isthmuses, obturating them with five different sealers, and performing standardized retreatment procedures. The amount of remaining filling material could be assessed using confocal microscopy, allowing for direct visualization and comparison among the sealers. By focusing specifically on the isthmus areas, the study successfully quantified the remnants left by each material, providing insight into their retreatability and highlighting differences in removal efficiency among the tested sealers.

All endodontic sealers evaluated left remnants of obturation material after the endodontic retreatment procedures. Besides, the percentage of remnant filling material in the root canals directly correlated with the root canal thirds; the closer to the apical region, the greater the amount of remnants. This is the first study analyzing the removal of Bio-C Sealer in a simulated retreatment condition; however, a previous study [20] reported that the use of the XP-endo Finisher R file was more effective in removing Bio-C Sealer cement from oval canals of mandibular premolars when compared to ultrasound-activated irrigation and EndoActivator (Dentsply Maillefer) . However, a differentiation between the main root canal and isthmuses was not performed in their work. Studies [21–23] indicate higher solubility for the ready-to-use Bio-C Sealer, theoretically facilitating its removal during endodontic retreatment. Although the setting behavior of calcium silicate-based sealers was not evaluated during obturation in this study, the expected setting was not observed. This may be related to the influence of isthmuses in mesial roots on local humidity and the possibility of incomplete canal drying before obturation. These factors could have affected the sealer's setting reaction. Further studies are needed to investigate how anatomical variations and different drying protocols impact the clinical setting behavior of calcium silicate-based sealers.

A previous study [24] found a greater amount of remnant for AH Plus in comparison with the EndoSequence BC Sealer HiFlow in the apical 4-mm section; conversely, here, similar results for these materials were observed at this level. At the 2-mm section of the root canal, AH Plus Jet had the highest percentage of remnants when compared to other materials, corroborating with a previous study [9], but diverging from the findings of others [6], since these report no statistically significant difference between the remnants of AH Plus Jet, BioRoot RCS, and EndoSequence BC Sealer HiFlow when removed by different endodontic instruments. This high permanence of AH Plus Jet remnants in root canals and isthmus regions may be associated both with its composition, as it is a resin-based material, and with its low solubility, which is directly correlated with many other physicochemical properties, when compared to other materials, such as BioRoot RCS, Bio-C Sealer, and EndoSequence BC Sealer [23].

The evaluation of the remnant filling material in root canals is a topic previously discussed [4,6,7,11,18]; however, isthmuses were not regarded in previous studies. This anatomical occurrence deserves attention since it is included as a factor for failure in endodontic procedures due to its insufficient preparation during endodontic instrumentation [19,25]. Here, the isthmus regions of 4- and 2-mm from the apex showed similar results for the remnant filling material. A previous research [26] used microcomputed tomography and passive ultrasonic irrigation with EndoSeal MTA (Maruchi, Wonju, Korea) and AH Plus Jet and showed comparable remnants for both cements, whereas in the present study, which employed XP-endo Finisher R, different results were found, highlighting the influence of instrumentation on results. The XP-endo Finisher R, with its flexibility, tip design, and expansion movement, likely played a key role in improving the removal of filling material, especially in isthmus areas. These mechanical properties are crucial for enhancing cleaning efficiency in complex anatomies, and further development towards this performance to be added to the endodontic armamentarium is highly welcome.

In the present study, ready-to-use materials had similar percentages in relation to the amount of remnant filling material in the isthmus region. No previous works were carried out analyzing canals and isthmuses individually; however, the use of a complementary instrument for cleaning and removing filling material from the root canal system was previously reported [22], mainly focusing on isthmus areas. Individual assessment of root canals and isthmuses is important because these anatomical regions present distinct challenges during retreatment. Evaluating them separately provides a clearer understanding of cleaning effectiveness, highlights persistent difficulties, and helps optimize techniques for more complete filling material removal. The complementation of endodontic instrumentation during retreatment seems to be highly recommended, as reported by previous studies [21,23,24].

The retreatment time analysis showed that canal patency was reestablished in all specimens after endodontic retreatment. Considering the retreatment time, AH Plus Jet had a longer retreatment time when compared to all other evaluated materials, which contrasts with the results of previous studies [8,27]. Although those studies did not relate the retreatment time to the presence or absence of isthmuses, this divergence may lie in their use of single-rooted canals without curvatures.

The association between the composition of endodontic sealers and their physicochemical properties is utterly dependent on a predictable setting of the material [24]. The setting time analysis performed here using two methods is justified by the high variances of the setting reaction of ready-to-use sealers, since the humidity of the dentinal tubules is an essential factor for its hydration and the complete setting reaction [28]. Under *in vitro* controlled humidity conditions, it is notable that the ambient humidity condition has significant effects on calcium silicate-based materials. The powder and liquid calcium silicate-based sealers, BioRoot RCS and MTApex, did not show a statistically significant difference between them for the moist method, whereas the opposite occurs in the dry method. Corroborating with the findings for BioRoot RCS [29] sealer, but contrasts with MTApex Sealer [19], probably due to different testing conditions between these studies. For EndoSequence BC Sealer HiFlow and Bio-C Sealer, the results presented here corroborated the results from previous studies [30]. In a clinical setting, this moisture-dependent setting reaction makes it unreliable for use, especially in situations of endodontic procedures where there is no certainty about the remaining moisture in the root canal.

The remnant filling material analysis after endodontic retreatment, here performed, potentially poses a methodological limitation, since a full volume remnant analysis using a three-dimensional method would be applicable [31]. However, to quantify the remnant filling material using confocal microscopy, 2-mm-thick sections were used to overcome the limitation of lacking three-dimensional analysis. Corroborative analysis between confocal microscopy and microcomputed tomography is warranted. Besides, another limitation of this study is the use of rhodamine B as a fluorophore for detecting filling material remnants. Although recent literature highlights that rhodamine B may not be ideal for the tested sealers due to its moisture affinity, potentially leading to overestimated staining, these findings primarily concern moist dentinal tubules. In the present study, the assessment focused on the isthmus, a region intentionally dried with paper cones following each manufacturer's guidelines, including those for ready-to-use sealers. Nonetheless, despite the dry conditions, the possibility of altered staining behavior remains; thus,

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this must be taken into consideration while interpreting the results presented here.

CONCLUSIONS

In conclusion, this *in vitro* evaluation demonstrated that filling material remnants persist in both the canals and isthmus regions of mesial roots of mandibular molars after endodontic retreatment, irrespective of the sealer used. Notably, AH Plus Jet required the longest retreatment time, while Bio-C Sealer exhibited the shortest. Furthermore, the setting time of calcium silicate-based sealers was significantly influenced by humidity conditions, highlighting a potential limitation in clinical applications where moisture control can be challenging. Clinically, this suggests that clinicians should be aware of the potential for residual filling material and the variable retreatability of different sealers when planning endodontic retreatment procedures.

CONFLICT OF INTEREST

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

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AUTHOR CONTRIBUTIONS

Conceptualization, Resources: Marciano MA, Alencar DSB. Data curation, Investigation, Methodology, Validation: all authors. Formal analysis: Alencar DSB, Marciano MA, Pelepenko LE. Funding acquisition, Visualization: Alencar DSB, Marciano MA. Project administration: Marciano MA, Duarte MAH, Alencar DSB, Pelepenko LE. Supervision: Marciano MA. Writing - original draft: Alencar DSB, Marciano MA. Writing - review & editing: Moraes BF, Janini ACP, Pelepenko LE. All authors read and approved the final manuscript.

DATA SHARING STATEMENT

The datasets are not publicly available but are available from the corresponding author upon reasonable request.

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Research Article

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Comparison of YouTube, TikTok, and Instagram as digital sources for obtaining information about pulp therapy in primary and permanent teeth

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ABSTRACT

Objectives: This study aimed to compare the content, educational quality, and dependability of videos on Instagram, TikTok, and YouTube about pulp therapy (PT) in pediatric dentistry and endodontics.
Methods: Three popular video sites, Instagram (Meta Platforms, Inc.,), TikTok (ByteDance Ltd.), and YouTube (Google LLC), were searched for PT content to analyze for compliance with the American Association of Endodontists and American Academy of Pediatric Dentistry guidelines for clinical endodontists and pediatric dentists. The searched hashtags were #pulpaltherapy, #pulpaltreatment, #pulptherapy, and #pulptreatment. The classification of 158 English-language videos was based on several variables: communication quality, duration, likes and dislikes, views, source, treatment, and genre. The videos were evaluated using a usefulness score and the Global Quality Scale (GQS), Video Information and Quality Index (VIQI), Journal of the American Medical Association (JAMA) score, and modified DISCERN score to rate their quality and reliability. The majority of the videos were published by healthcare professionals, dental clinics, and universities.
Results: Significant relationships existed between video length, source of upload, usefulness score, tooth type, pulp status, and VIQI, JAMA, GQS, and DISCERN scores for all three platforms ($p < 0.05$). A statistically significant relationship existed of YouTube, TikTok, and Instagram with the number of views, number of months since upload, view rates, comments and likes ($p < 0.05$).
Conclusions: TikTok and Instagram reel videos provided high- to moderate-quality information about PT, especially in children, but YouTube may provide more reliable information than other social media tools.

Keywords: Primary and permanent teeth; Pulp therapy; Pulpal treatment; Instagram; TikTok; YouTube

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INTRODUCTION

Pulp therapy (PT) aims to preserve the health and integrity of teeth, along with their supporting tissues, in cases of caries, traumatic injury, or other underlying factors affecting a tooth. Various therapeutic interventions are involved in PT depending on the diagnosis of pulp health or pathology for both primary and permanent teeth [1]. Properly performed PT at the right time prevents potential problems arising from tooth loss by enabling the tooth to remain in the dental arch. The successful implementation of PT is directly associated with the clinician's clinical experience and theoretical knowledge [2]. Dental professionals are also responsible for providing accurate information to their patients. However, medical information sources are rapidly changing for both patients and healthcare professionals [3].

During the coronavirus disease 2019 (COVID-19) pandemic, social media has become an increasingly widespread method for people to obtain medical information [4]. To prevent the spread of the novel coronavirus, the suspension of practical applications and face-to-face education, particularly in the field of dentistry, has directed students towards completing their medical education through the use of internet platforms [5]. To obtain medical information, dental and medical professionals often rely on a range of educational methods, with social media platforms such as Wikipedia (Wikimedia Foundation, San Francisco, CA, USA), YouTube (Google LLC, Mountain View, CA, USA), and Facebook (Meta Platforms, Inc., Menlo Park, CA, USA) being among the most prominent [6].

YouTube, the second most-visited online platform, has been recognized as a highly effective way of disseminating crucial health-related information to communities, providing valuable access to such information for both healthcare professionals and individuals [7]. However, information on YouTube may not always be scientifically accurate, and some misleading information might have adverse effects on patients' health [8]. Recently, TikTok (ByteDance Ltd., Beijing, China) has emerged as a popular platform like YouTube for the dissemination of personal or health-related experiences. Owing to its low cost, widespread popularity, and increasing adoption by healthcare professionals, TikTok serves as an accessible platform for individuals seeking medical advice. This has led to increasing interest in studies examining the quality of videos on TikTok [9]. Since its inception in 2010, Instagram (Meta Platforms, Inc., Menlo Park, CA, USA) has experienced particularly remarkable growth, emerging as one of the most popular social media platforms. Instagram is becoming a popular platform for marketing, advertising, activism, and news updates across a range of businesses, including higher education [10].

A significant body of research has analyzed the content of medical and dental information videos on YouTube [7,8,10,11], whereas studies related to TikTok [3,9,12], and Instagram are limited [13]. To date, no study has comprehensively analyzed the quality of YouTube, TikTok, and Instagram videos related to PT. The primary objective of this study was to evaluate the reliability, quality, and content of PT-related videos across these three platforms and to compare them with one another.

METHODS

The data used in this study were freely accessible and did not include clinical or animal experimentation data, including specifics, photos, or patient questionnaires. Consequently, neither informed consent nor clearance from the ethics committee was required. This study is a comparison and analysis of the videos uploaded on social media platforms like YouTube, TikTok, and Instagram; therefore, we do not have any human participants, a clinical trial number, or ethical approval.

Study design and data

A cross-sectional study design was employed to assess the educational value of videos available on YouTube, TikTok, and Instagram. To identify the most frequently used search terms, the Google Trends platform (Google LLC; https://trends.google.com) was utilized [14]. In this study, the search parameters were set to "worldwide" and limited to data from the past 5 years. Possible hashtags related to children's oral health, such as #pulptherapy, #pulptreatment, #pulpaltherapy, and #pulpaltreatment were used in three video platform

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searches conducted between 7:00 am and 9:00 pm on March 11 to 12, 2024 (Figure 1).

Videos relevant to PT were found using the unfiltered default settings. After manually reviewing the first 361 PT-related videos on YouTube, 275 on TikTok, and 224 on Instagram, relevant information was extracted, documented, and scored using Microsoft Excel (Microsoft Corp., Redmond, WA, USA). All pop-ups and historical data in the browser history were deleted before the hashtag search was performed. The top 158 videos were reviewed for relevance for all video platforms (Figure 2).

Analysis of videos

Initial scanning of all videos (860 videos) was performed by two experienced specialists (HGG and EK) (Figure 3). Then, two researchers (MGE and DNO) evaluated the videos independently. Among the researchers, two were PhD students and the other two were specialists with 10 years of experience in endodontics and pediatric dentistry; all of them possessed profound expertise in pulpal treatment, pulp capping, pulpectomy, apexification, apexogenesis, and regenerative endodontics.

Videos unrelated to PT, duplicates, those lacking audio, narration, or graphics, non-English content, incomprehensible speech, or those outside the specified duration limits were excluded (Figure 2). Each video was meticulously analyzed to gather information on views, likes, dislikes, comments, duration (in seconds), time since upload, country of origin (Figure 4), upload source, video category, and gender of the uploader. To mitigate bias, counts for likes, dislikes, and comments were conducted (by MGE and DNO) subsequent to viewing each video. Viewer engagement metrics were assessed using the interactive index (as the difference between likes and dislikes divided by total views, multiplied by 100) and view rate (determined by dividing views by months since upload, multiplied by 100).

Uploaders were categorized under five headings: (1) healthcare professionals (endodontist, pediatric dentist, dentist), (2) hospitals, universities, and dental clinics, (3) commercial (dental manufacturing or supply companies), (4) laypersons, and (5) others (television channels or news agencies) [15]. Video types were recorded in four groups: (1) educational, (2) patient testimonial (reference), (3) product advertising, and (4) entertainment [16]. The videos were also grouped by length: 0–15 seconds, 15–30 seconds, 30–45 seconds, and >45 seconds [17].

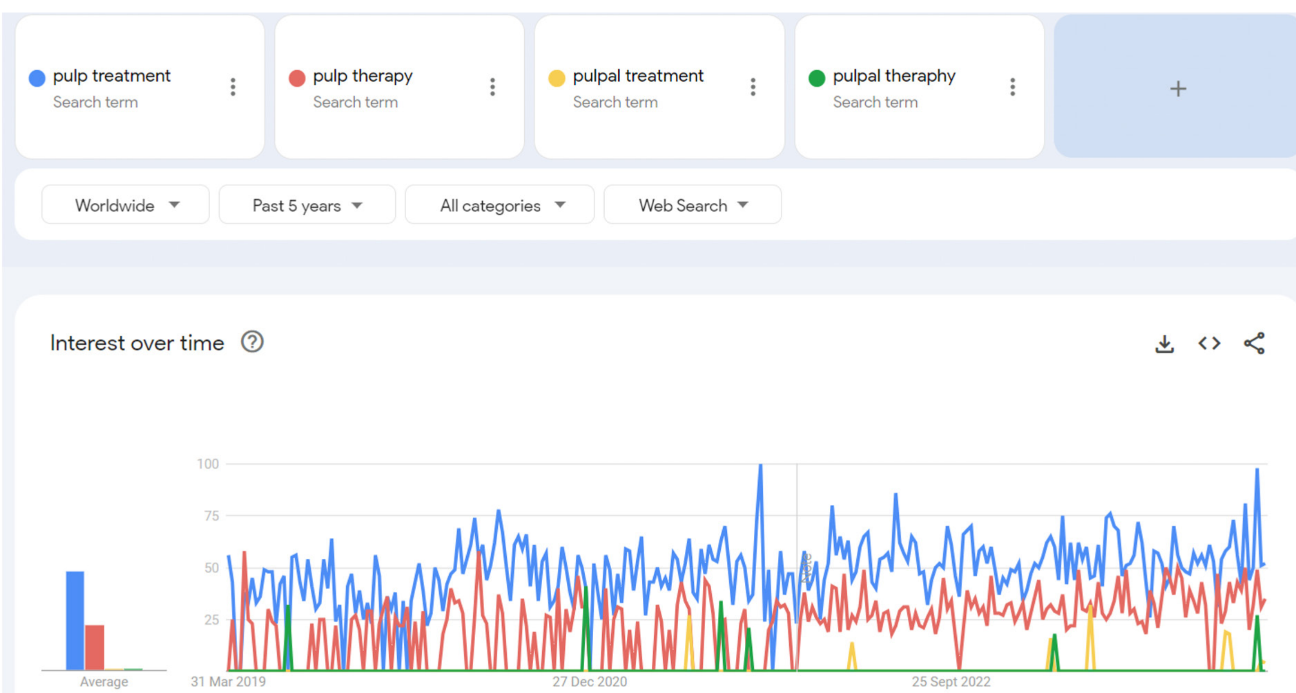

Figure 1. Appearance of hashtags in Google Trends [14].

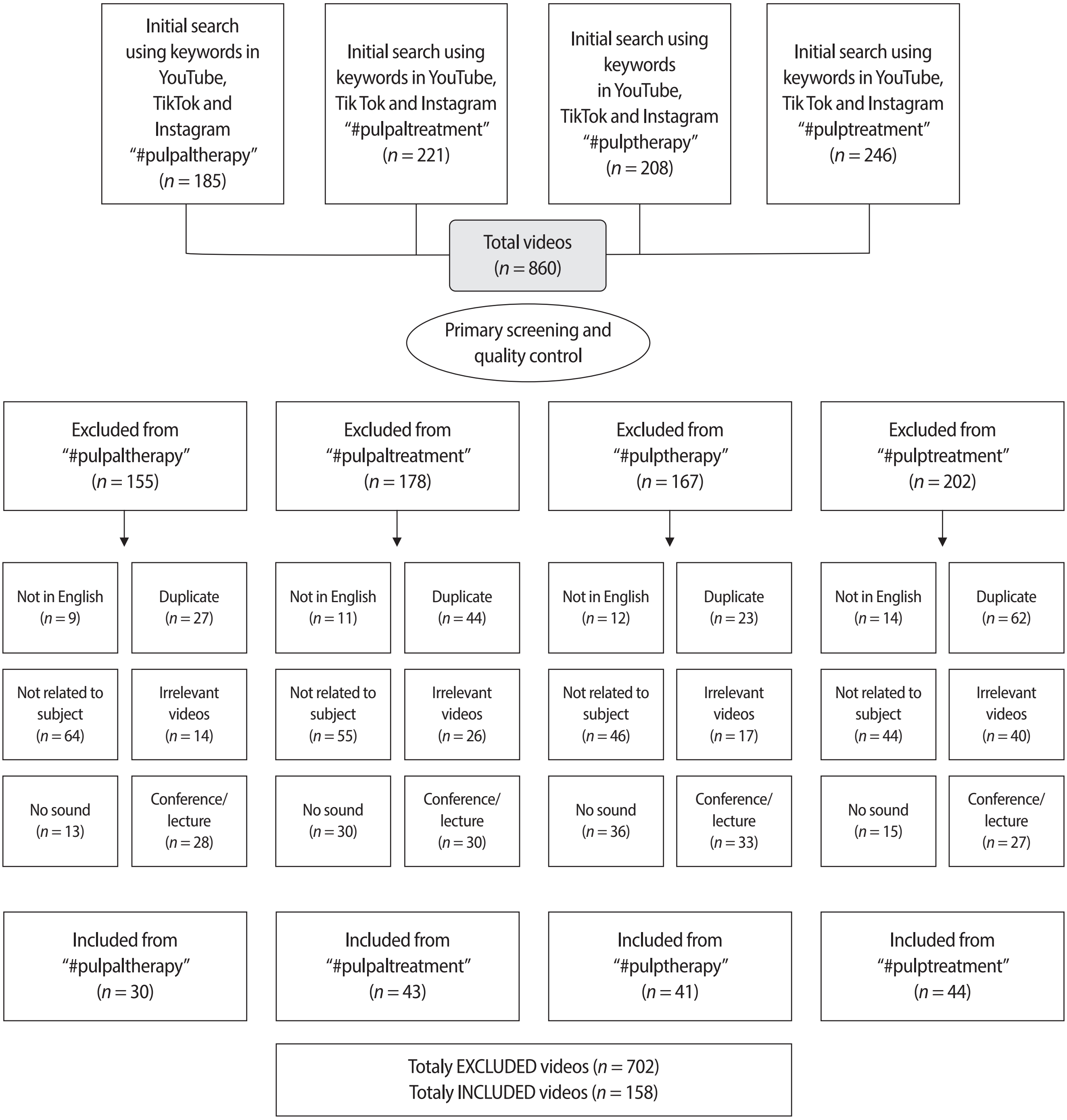

Figure 2. Flow diagram of the data detected from the video platforms. YouTube: Google LLC, Mountain View, CA, USA. TikTok: ByteDance Ltd., Beijing, China. Instagram: Meta Platforms, Inc., Menlo Park, CA, USA.

After reviewing the relevant literature, we identified the fundamental aspects of PT [18–20]. Subsequently, we conducted an analysis of videos on YouTube, TikTok, and Instagram to delineate the content topics addressed, such as (1) definition of PT in permanent and primary teeth, (2) indications of PT, (3) contraindications of PT, (4) objectives, (5) required materials and equipment, (6) benefits and drawbacks, (7) radiographic evaluation, (8) procedure steps, (9) bleeding control, (10) use of rubber dams, (11) cavity disinfection, (12)

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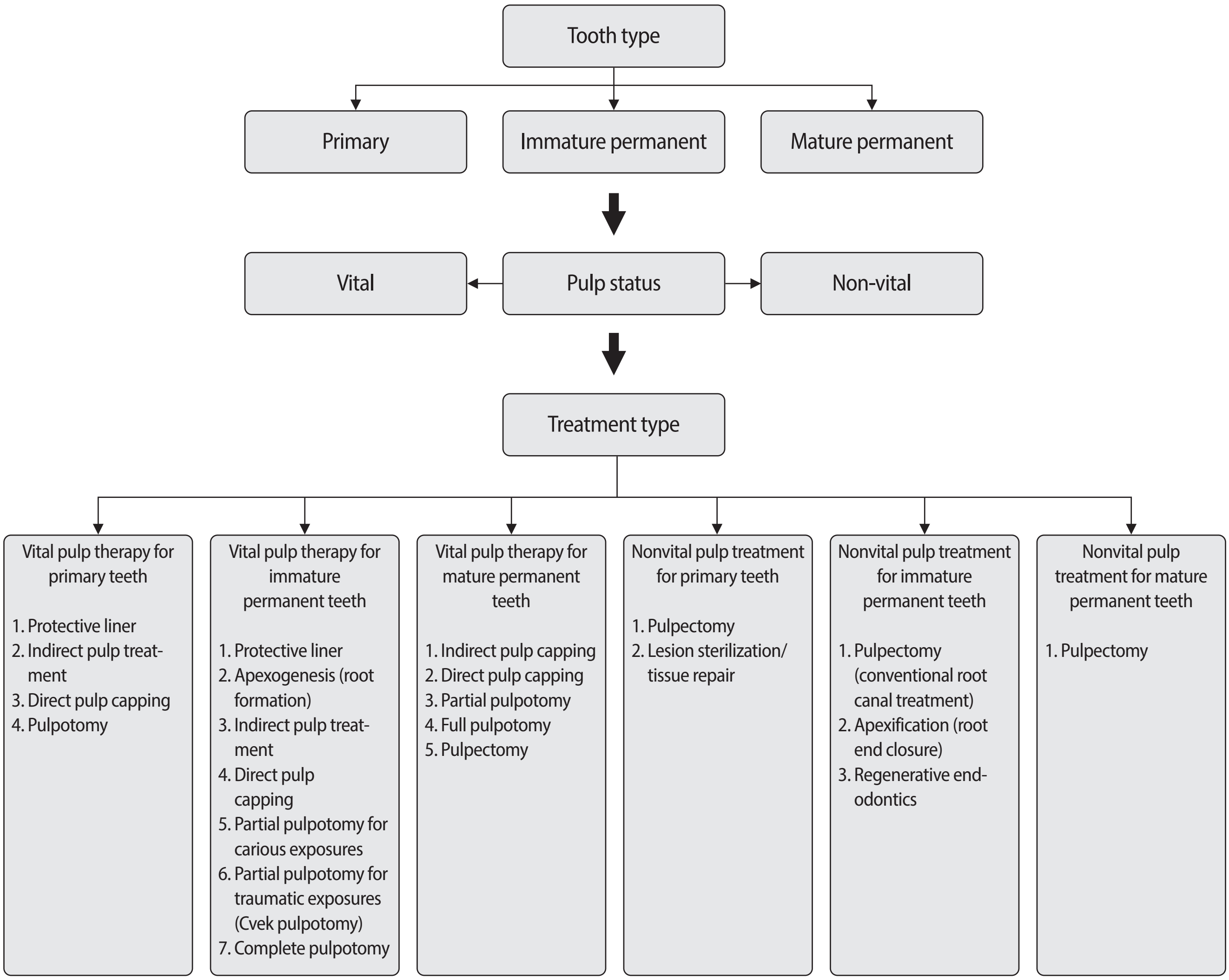

Figure 3. Study design of the selection video situation.

restorability of the tooth, (13) possible complications, (14) pain and symptoms that may occur after treatment, and (15) alternative treatments. Each of these 15 items contributed 1 point to the total content score, yielding a maximum possible score of 15. Content scores were categorized as low (0–5 points), medium (6–10 points), or high (11–15 points).

Additionally, videos were stratified into three groups according to communication quality. Group 1 included videos without complementary images; Group 2 included videos with minimal complementary images (e.g., a single image); and Group 3 included videos with extensive use of complementary images (e.g., moving images or multiple images) [17].

Evaluation of videos regarding quality and reliability, four scoring systems: the modified DISCERN tool, the Global Quality Scale (GQS), the Video Information and Quality Index (VIQI), and the Journal of American Medical Association (JAMA) score were used. To assess the quality and reliability of written health information regarding treatment options, the DISCERN toolkit (http://www.discern.org.uk/discern_instrument.php) was utilized. This standardized instrument comprises 15 questions, each rated on a scale from 1 (poor) to 5 (excellent) [21].

The GQS is a 5-point ordinal scale that evaluates the quality of information provided by the analyzed videos based on accessibility, relevance to patients, and overall

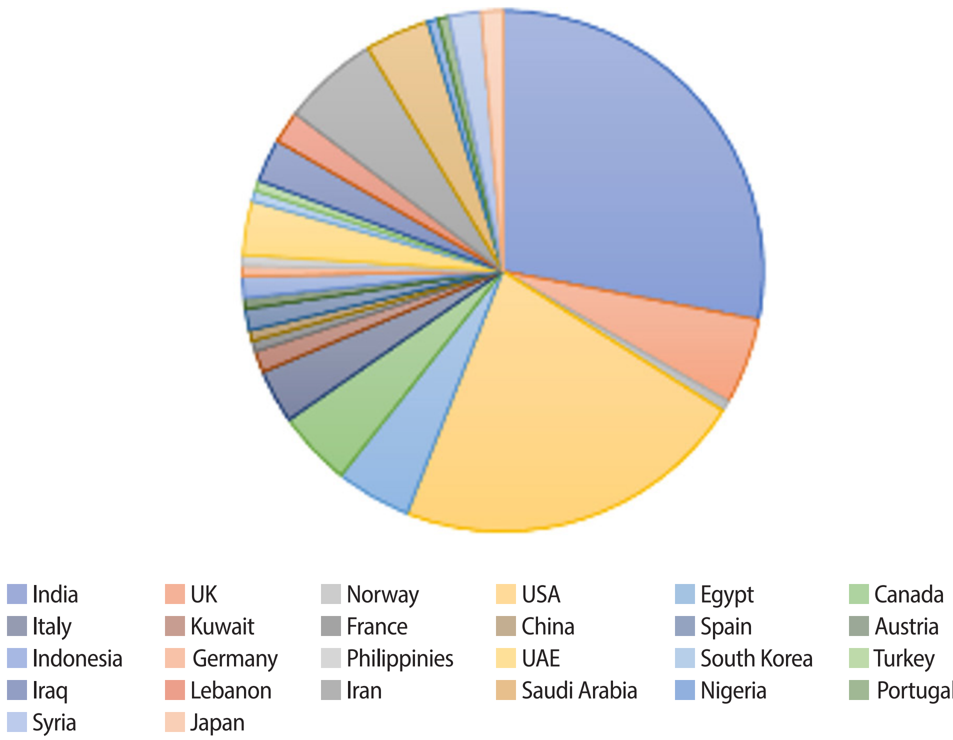

Figure 4. Pie chart of country origin uploaded videos.

caliber. The scale comprises five questions, each corresponding to a different quality level: very poor quality (1 point), somewhat poor quality with limited utility (2 points), average quality (3 points), satisfactory quality (4 points), and outstanding quality (5 points) [22].

The VIQI employs a 5-point Likert scale to assess both the quality and content of videos, with higher scores indicating superior quality. Each video was evaluated based on information flow, accuracy, and overall quality. Additionally, the presence of features such as still images, animations, community interviews, video covers, and report summaries contributed 1 point each to the overall score. Accuracy was specifically determined by examining the consistency between the video's title and its actual content [23].

Data collected from the videos were assessed using JAMA scores, which encompass four criteria: authorship, citation, description, and currency. Each criterion is rated on a scale from 0 to 4, where a score of 0 indicates that the material fails to meet the specified criteria, while a score of ≥1 indicates compliance. Higher scores indicate greater information quality [24].

Statistical analysis

This study provided descriptive statistics (count, percentage, mean, standard deviation, and median). The assumption of normal distribution was checked using the Shapiro-Wilk test. For comparisons between two groups with non-normally distributed data, the Mann-Whitney *U* test was applied. For comparisons among three or more groups with non-normally distributed data, the Kruskal-Wallis test was conducted to compare group means. The *post hoc* Bonferroni test was used to identify which group or groups were responsible for any observed differences. When the assumption of sample size (expected value, >5) for testing the relationship between categorical variables was not met, the Fisher exact test was performed. The relationships between continuous variables were examined using the Spearman correlation, and the relationships between a continuous variable and an ordinal categorical variable were examined using the Kendall tau correlation. The analyses were conducted using IBM SPSS version 25.0 (IBM Corp, Armonk, NY, USA).

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RESULTS

The correlation coefficients (Cohen's Kappa) between the initial and repeat measurement values exceeded the threshold of 0.70 (YouTube, 0.904–0.996; TikTok, 0.791–0.975; and Instagram, 0.856–0.973). Since the *p*-values were less than the alpha value of 0.05, statistically significant, positive, and very high-level relationships were obtained. Therefore, the measurements were stable and consistent. The videos obtained for the study could not be used because some did not meet the requirements: 17.5% of YouTube videos were used, along with 10.2% of TikTok videos and 45.3% of Instagram videos.

As a result of the analyses, statistically significant relationships were identified between social media type and video length; source; VIQI, JAMA, and GQS scores; DISCERN section 1; tooth type; pulp status; and usefulness score ($p < 0.05$). No statistically significant relationship existed between social media type and video type ($p > 0.05$) (Table 1).

Statistically significant differences were found among social media types for the number of views, number of months since upload, number of comments, number of likes, viewing rate, usefulness score, DISCERN section 2, and total DISCERN scores ($p < 0.05$). For the number of views, number of comments, and number of likes, statistically significant differences were identified between Instagram and YouTube and between Instagram and TikTok ($p < 0.05$). The number of views, comments, and likes on YouTube and TikTok was higher than for Instagram. No statistically significant difference was found in DISCERN section 1 scores according to the type of social media ($p > 0.05$) (Table 2).

The distribution and comparison of video characteristics according to VIQI scores are shown in Table 3. For YouTube, Instagram, and TikTok, statistically significant differences were found in usefulness, DISCERN section 1, and total DISCERN scores based on VIQI scores ($p < 0.05$).

A comparison of video characteristics according to JAMA scores is presented in Table 4. Statistically significant differences were observed among usefulness, DISCERN section 1, DISCERN section 2, and total DISCERN scores according to JAMA scores in YouTube and TikTok videos ($p < 0.05$). For Instagram videos, statistically significant differences were found among the number of days since upload, usefulness, DISCERN section 1, and total DISCERN scores according to JAMA scores ($p < 0.05$).

Table 5 presents the distribution and comparison of video characteristics according to GQS scores. In YouTube, TikTok, and Instagram videos, statistically significant differences were observed among usefulness, DISCERN section 1, DISCERN section 2, and total DISCERN scores based on GQS scores ($p < 0.05$). Table 6 shows the distribution and comparison of video characteristics according to the usefulness score. The analysis revealed statistically significant differences among DISCERN section 1, DISCERN section 2, and total DISCERN scores of only YouTube videos according to usefulness scores ($p < 0.05$).

DISCUSSION

PT is performed often in dental offices, dental clinics, and university hospitals on both adult and pediatric patients, with an estimated prevalence of 9.6%, though many cases go unreported [25,26]. During childhood, determining and selecting appropriate treatment options for PT in both permanent and primary teeth can pose challenges, particularly when evaluating the extent and location of tooth decay [27]. Treatment success generally depends on the correct evaluation of clinical and radiological findings. Therefore, condition management and appropriate treatment plans commonly provided by international guidelines are important for a better prognosis [20].

Social media has become an increasingly widespread source of information. It can also be preferred as a source of health content due to its ease of use, speed, and significant impact on society [28]. During the COVID-19 pandemic, many dental schools quickly adapted to online and virtual learning platforms to ensure students could continue their education. This shift was necessary due to curfews, social distancing, and the closure of many face-to-face academic and clinical settings. While these tools were crucial to ensure continuity of education, they were challenging for many students, especially for the practical skills required in dentistry [29,30]. Although audiovisual content has a powerful

Table 1. Distribution and comparison of relevant features according to social media platforms

Variable	*n* (%)			Test statistics	*p*-value
	YouTube	TikTok	Instagram		
Video length (sec)				33.395	<0.001*
15–30	0 (0)	3 (10.7)	1 (1.6)		
30–45	2 (3.2)	6 (21.4)	18 (29.0)		
>45	61 (96.8)	16 (57.1)	43 (69.4)		
Source of upload				18.502	0.006*
Healthcare professionals	39 (61.9)	23 (82.1)	47 (75.8)		
Hospital/university/dental clinics	4 (6.3)	0 (0)	6 (9.7)		
Commercial	11 (17.5)	1 (3.6)	9 (14.5)		
Layperson	1 (1.6)	0 (0)	0 (0)		
Others	8 (12.7)	4 (14.3)	0 (0)		
Video type				9.743	0.066
Educational	53 (84.1)	25 (89.3)	60 (96.8)		
Patient testimonial	4 (6.3)	0 (0)	2 (3.2)		
Product advertisement	4 (6.3)	1 (3.6)	0 (0)		
Entertainment	2 (3.2)	2 (7.1)	0 (0)		
VIQI				46.196	<0.001*
Score 1	9 (14.3)	4 (14.3)	8 (12.9)		
Score 2	24 (38.1)	16 (57.1)	53 (85.5)		
Score 3	19 (30.2)	8 (28.6)	1 (1.6)		
Score 4	11 (17.5)	0 (0)	0 (0)		
JAMA				61.096	0.001*
Score 1	27 (42.9)	9 (32.1)	4 (6.5)		
Score 2	19 (30.2)	19 (67.9)	58 (93.5)		
Score 3	10 (15.9)	0 (0)	0 (0)		
Score 4	7 (11.1)	0 (0)	0 (0)		
GQS				35.519	<0.001*
Score 1	16 (25.4)	1 (3.6)	0 (0)		
Score 2	23 (36.5)	17 (60.7)	32 (51.6)		
Score 3	10 (15.9)	4 (14.3)	23 (37.1)		
Score 4	10 (15.9)	6 (21.4)	7 (11.3)		
Score 5	4 (6.3)	0 (0)	0 (0)		
Tooth type				9.725[a)]	0.045*
Primary	6 (9.5)	2 (7.1)	5 (8.1)		
Immature permanent	21 (33.3)	2 (7.1)	11 (17.7)		
Mature permanent	36 (57.1)	24 (85.7)	46 (74.2)		
Pulp status				29.041	<0.001*
Vital	39 (61.9)	3 (10.7)	41 (66.1)		
Non-vital	23 (36.5)	22 (78.6)	19 (30.6)		
Vital and non-vital	1 (1.6)	3 (10.7)	2 (3.2)		
DISCERN 16				31.093	<0.001*
Low	20 (31.7)	6 (21.4)	1 (1.6)		
Score 2	19 (30.2)	13 (46.4)	31 (50.0)		
Moderate	11 (17.5)	6 (21.4)	23 (37.1)		
Score 4	10 (15.9)	3 (10.7)	7 (11.3)		
High	3 (4.8)	0 (0)	0 (0)		
Usefulness				34.119	<0.001*
Low	25 (39.7)	24 (85.7)	49 (79.0)		
Medium	25 (39.7)	4 (14.3)	13 (21.0)		
High	13 (20.6)	0 (0)	0 (0)		

GQS, Global Quality Scale; JAMA, Journal of the American Medical Association; VIQI, Video Information and Quality Index.
YouTube: Google LLC, Mountain View, CA, USA. TikTok: ByteDance Ltd., Beijing, China. Instagram: Meta Platforms, Inc., Menlo Park, CA, USA.
[a)]Pearson chi-square test.
*$p < 0.05$.

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Table 2. Distribution and comparison of relevant features according to social media platforms

Variable	YouTube	TikTok	Instagram	Test statistics	*p*-value
Number of views	479,180.94 ± 1,534,013.86 (24,378)	1,733,354.64 ± 8,178,266.69 (28,400)	4,444.18 ± 6,117.09 (1,599)	25.389	<0.001*
Time since upload (mo)	52.11 ± 42.06 (40)	11.75 ± 11.26 (7)	12.03 ± 8.85 (10)	74.382	<0.001*
Number of comments	367.38 ± 1,710.56 (9)	223.07 ± 779.02 (8.5)	7.45 ± 13.68 (2)	14.901	0.001*
Number of likes	1,953.32 ± 5,837.96 (281.5)	31,320.71 ± 109,900.76 (323)	162.75 ± 265.22 (59)	9.684	0.008*
Viewing rate	1,843,026.82 ± 6,777,739.1 (63,990)	19,110,127.04 ± 90,844,556.8 (248,166.67)	113,127.31 ± 220,988.68 (15,608.49)	17.149	<0.001*
Usefulness	6.97 ± 3.55 (6)	3.71 ± 1.76 (4)	4.45 ± 1.8 (4)	29.710	<0.001*
DISCERN section 1	20.65 ± 7.82 (20)	18.71 ± 6.41 (18)	17.35 ± 6.37 (16)	4.073	0.131
DISCERN section 2	17.25 ± 6.53 (15)	12.78 ± 4.35 (12)	10.97 ± 3.34 (10)	43.107	<0.001*
Total DISCERN	38.06 ± 13.22 (35)	31.7 ± 10.23 (29)	29.61 ± 7.18 (28.5)	18.178	<0.001*

Values are presented as mean ± standard deviation (median).
YouTube: Google LLC, Mountain View, CA, USA. TikTok: ByteDance Ltd., Beijing, China. Instagram: Meta Platforms, Inc., Menlo Park, CA, USA.
**p* < 0.05.

Table 3. Distribution and comparison of video characteristics according to VIQI scores

VIQI score	YouTube	Test statistics/ *p*-value	TikTok	Test statistics/ *p*-value	Instagram	Test statistics/ *p*-value
Number of views		4.705/0.195		2.078/0.354		3.747/0.154
Score 1	22,982.22 ± 36,853.51 (6,399)		21,537.5 ± 25,013.85 (15,051.5)		21.000 ± 0 (21.000)	
Score 2	802,462.1 ± 2,176,896 (23,198)		286,126.5 ± 555,202.3 (24.850)		3,844.13 ± 5,513.04 (1,540)	
Score 3	508,819.7 ± 1,305,315 (24,311)		5,483,720 ± 15,322,667 (53.150)		7.090 ± 0 (7.090)	
Score 4	95,899.45 ± 144,939.6 (37,650)		-		-	
Time since upload (mo)		1.028/0.795		3.838/0.147		5.801/0.055
Score 1	38.67 ± 25.26 (37)		17.25 ± 16.17 (10.5)		16.25 ± 9.5 (14.5)	
Score 2	61.92 ± 54.87 (38)		13.31 ± 11.67 (10.5)		10.72 ± 7.09 (9)	
Score 3	49.47 ± 39.15 (42)		5.88 ± 4.76 (4.5)		48 ± 0 (48)	
Score 4	46.27 ± 18.2 (39)		-		-	
Number of comments		3.670/0.299		1.256/0.534		3.399/0.183
Score 1	18.44 ± 30.72 (1)		6 ± 3.92 (5.5)		10 ± 16.74 (3)	
Score 2	665.21 ± 2,707.22 (6.5)		123.5 ± 275.32 (7.5)		6.08 ± 11.22 (2)	
Score 3	346.11 ± 682.95 (6)		530.75 ± 1.421.47 (22)		60 ± 0 (60)	
Score 4	39.82 ± 53.22 (27)		-		-	
Number of likes		6.598/0.086		1.222/0.543		2.697/0.260
Score 1	295.89 ± 485.03 (57)		284.5 ± 288.01 (275.5)		190.38 ± 289.45 (57.5)	
Score 2	1,900.09 ± 3,963.94 (87)		19,560.56 ± 51,370.47 (168)		143.27 ± 244.87 (57.5)	
Score 3	3,433 ± 9,569.03 (294)		70,359.13 ± 195,765.5 (603)		877 ± 0 (877)	
Score 4	864.91 ± 617.09 (785)		-		-	

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Table 3. Continued

VIQI score	YouTube	Test statistics/ *p*-value	TikTok	Test statistics/ *p*-value	Instagram	Test statistics/ *p*-value
Viewing rate		3.827/0.281		4.738/0.094		1.374/0.503
Score 1	66,352.09 ± 99,911.14 (15,734.88)		130,034.8 ± 174,827 (55,091.11)		210,000 ± 0 (210,000)	
Score 2	3,237,364 ± 9,485,577 (67,051.76)		1,888,423 ± 3,131,300 (221,061.4)		113,173.7 ± 226,653.7 (14,089.74)	
Score 3	1,868,451 ± 6,114,836 (63.940)		63,043,581 ± 169,000,000 (907,500)		14,770.83 ± 0 (14,770.83)	
Score 4	210,565.9 ± 342,149.3 (96,538.46)		-		-	
Usefulness		31.307/<0.001*		13.714/0.001*		11.283/0.004*
Score 1	3.44 ± 1.67 (4)		1.75 ± 0.5 (2)		3 ± 0.53 (3)	
Score 2	6.00 ± 2.09 (6)		3.38 ± 1.2 (4)		4.58 ± 1.74 (4)	
Score 3	6.79 ± 3.1 (7)		5.37 ± 1.77 (5)		9 ± 0 (9)	
Score 4	12.27 ± 2 (13)		-		-	
DISCERN section 1		21.271/<0.001*		16.445/<0.001*		11.609/0.003*
Score 1	15.44 ± 4.64 (16)		11.75 ± 2.63 (12.5)		13.38 ± 1.6 (13.5)	
Score 2	17.42 ± 4.02 (17.5)		16.56 ± 4.02 (17)		17.77 ± 6.54 (18)	
Score 3	20.68 ± 6.05 (22)		26.5 ± 3.66 (27.5)		27 ± 0 (27)	
Score 4	31.91 ± 8.37 (33)		-		-	
DISCERN section 2		26.198/<0.001*		10.685/0.005*		2.600/0.273
Score 1	11.00 ± 2.55 (10)		8.5 ± 2.38 (7.5)		9.75 ± 1.39 (10)	
Score 2	15.21 ± 3.99 (15)		11.87 ± 2.85 (12)		11.02 ± 3.41 (10)	
Score 3	18.00 ± 5.29 (19)		16.63 ± 4.75 (16)		18 ± 0 (18)	
Score 4	25.55 ± 7.1 (27)		-		-	
Total DISCERN		27.794/<0.001*		15.937/<0.001*		13.672/0.001*
Score 1	26.44 ± 6.44 (27)		20.25 ± 4.57 (20)		23.13 ± 2.53 (24)	
Score 2	33.04 ± 5.82 (33)		28.67 ± 6.17 (28)		30.3 ± 6.93 (29)	
Score 3	38.68 ± 10.44 (40)		43.13 ± 7.75 (44)		45 ± 0 (45)	
Score 4	57.45 ± 13.44 (56)		-		-	

Values are presented as mean ± standard deviation (median).
VIQI, Video Information and Quality Index.
YouTube: Google LLC, Mountain View, CA, USA. TikTok: ByteDance Ltd., Beijing, China. Instagram: Meta Platforms, Inc., Menlo Park, CA, USA.
*$p < 0.05$.

Table 4. Distribution and comparison of video characteristics according to JAMA scores

JAMA score	YouTube	Test statistics/ *p*-value	TikTok	Test statistics/ *p*-value	Instagram	Test statistics/ *p*-value
Number of views		5.271/0.153		83.00/0.923		-
Score 1	378,109.4 ± 1,238,790 (6,766)		183,190.3 ± 457,782.9 (37,200)		-	
Score 2	990,449.4 ± 2,329,163 (119,172)		2,467,643 ± 9,922,817 (14,400)		4,444.18 ± 6,117.09 (1,599)	
Score 3	88,319.1 ± 157,050.4 (21,537.5)		-		-	
Score 4	39,673.71 ± 27,415.88 (37,650)		-		-	

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Table 4. Continued

JAMA score	YouTube	Test statistics/ *p*-value	TikTok	Test statistics/ *p*-value	Instagram	Test statistics/ *p*-value
Time since upload (mo)		0.599/0.897		67.50/0.383		38.00/0.022*
Score 1	52.78 ± 47.34 (37)		14.44 ± 13.02 (7)		22.25 ± 8.85 (24)	
Score 2	58.47 ± 48.35 (44)		10.47 ± 10.46 (6)		11.33 ± 8.47 (9.5)	
Score 3	45.3 ± 28.19 (40.5)		-		-	
Score 4	42 ± 6.14 (39)		-		-	
Number of comments		1.490/0.685		69.50/0.438		87.50/0.752
Score 1	149.11 ± 486.82 (4)		79.22 ± 220.82 (7)		3.75 ± 7.5 (0)	
Score 2	975.63 ± 3,027.77 (3)		291.21 ± 934.56 (19)		7.71 ± 14.01 (2)	
Score 3	40.3 ± 61.6 (16.5)		-		-	
Score 4	25.57 ± 11.76 (27)		-		-	
Number of likes		5.521/0.137		81.50/0.847		95.50/0.752
Score 1	2,329.85 ± 8,364.47 (76)		16,379.44 ± 48,091.81 (476)		155.5 ± 206.23 (68)	
Score 2	2,619.17 ± 3,545.8 (839.5)		38,398.16 ± 130,095.5 (147)		163.3 ± 270.73 (56)	
Score 3	609.5 ± 656.54 (384)		-		-	
Score 4	708.57 ± 513.75 (530)		-		-	
Viewing rate		6.060/0.109		84.00/0.962		-
Score 1	1,468,307 ± 5,495,980 (27,175.76)		951,094.8 ± 1,553,976 (250,000)		-	
Score 2	3,886,522 ± 10,354,536 (243,780)		27,711,774 ± 110,000,000 (246,333.3)		113,127.3 ± 220,988.7 (15,608.49)	
Score 3	189,657.2 ± 366,511.6 (61,617.56)		-		-	
Score 4	103,702.6 ± 80,932.86 (96,538.46)		-		-	
Usefulness		34.905/<0.001*		17.00/<0.001*		32.50/0.012*
Score 1	4.56 ± 1.91 (4)		2.22 ± 0.83 (2)		2.75 ± 0.5 (3)	
Score 2	6.63 ± 2.52 (6)		4.42 ± 1.64 (4)		4.57 ± 1.8 (4)	
Score 3	10 ± 2.75 (11)		-		-	
Score 4	12.86 ± 1.21 (13)		-		-	
DISCERN section 1		29.00/<0.001*		33.00/0.009*		29.50/0.00*
Score 1	16.48 ± 4.48 (17)		14.11 ± 3.66 (13)		12.5 ± 1.73 (12)	
Score 2	18 ± 4 (18)		20.89 ± 6.33 (20)		17.69 ± 6.44 (17)	
Score 3	27.3 ± 4.83 (28.5)		-			
Score 4	34.43 ± 8.14 (39)		-			
DISCERN section 2		26.683/<0.001*		19.50/0.001*		62.50/0.129
Score 1	13.93 ± 4.48 (13)		9.44 ± 2.01 (10)		8.75 ± 1.26 (9)	
Score 2	15.79 ± 4.21 (15)		14.44 ± 4.27 (14)		11.12 ± 3.39 (10.5)	
Score 3	20.6 ± 4.22 (21.5)		-		-	
Score 4	29.29 ± 5.47 (29)		-		-	
Total DISCERN		33.492/<0.001*		21.00/0.001*		10.00/<0.001*
Score 1	30.78 ± 7.39 (30)		23.56 ± 5.32 (22)		21.25 ± 2.06 (21)	
Score 2	33.79 ± 6.95 (34)		35.78 ± 9.7 (35.5)		30.19 ± 7.05 (29)	
Score 3	47.9 ± 6.64 (49.5)		-		-	
Score 4	63.71 ± 11.57 (69)		-		-	

Values are presented as mean ± standard deviation (median).
JAMA, Journal of the American Medical Association.
YouTube: Google LLC, Mountain View, CA, USA. TikTok: ByteDance Ltd., Beijing, China. Instagram: Meta Platforms, Inc., Menlo Park, CA, USA.
*$p < 0.05$.

Table 5. Distribution and comparison of video characteristics according to GQS scores

GQS score	YouTube	Test statistics/ *p*-value	TikTok	Test statistics/ *p*-value	Instagram	Test statistics/ *p*-value
Number of views		3.838/0.430		2.802/0.423		0.033/0.983
Score 1	151,005.4 ± 362,704.6 (6,582.5)		1.347 ± 0 (1.347)		-	
Score 2	517,674 ± 1,339,250 (8,968)		269,287.2 ± 541,128.1 (27,000)		4,621.56 ± 6,769.52 (1.540)	
Score 3	343,102.8 ± 664,023.6 (25,401)		67,486 ± 100,969.8 (27,318.5)		4,703.79 ± 6,261.99 (1,833)	
Score 4	1,225,580 ± 3,201,189 (5,6061.5)		7,280,793 ± 17.697.285 (53,150)		2,826 ± 2,929.19 (1,882)	
Score 5	44,744.75 ± 15,339.49 (45,169.5)		-		-	
Time since upload (mo)		1.656/0.799		2.714/0.438		2.250/0.325
Score 1	60.06 ± 49.6 (43.5)		7 ± 0 (7)		-	
Score 2	56 ± 48.22 (34)		15 ± 12.94 (14)		12.59 ± 7.58 (12)	
Score 3	41.9 ± 40.09 (31)		7 ± 6.78 (4.5)		10.26 ± 7.9 (7)	
Score 4	45.2 ± 20.19 (40.5)		6.5 ± 5.47 (5.5)		15.29 ± 15.62 (9)	
Score 5	40.75 ± 5.68 (39)		-		-	
Number of comments		6.491/0.165		2.131/0.546		0.259/0.879
Score 1	100.88 ± 169.14 (5.5)		2 ± 0 (2)		-	
Score 2	187.04 ± 570.49 (1)		115.59 ± 268.09 (8)		8 ± 13.92 (2)	
Score 3	196.8 ± 388.38 (22)		25.25 ± 45.24 (4)		5.48 ± 10.35 (2)	
Score 4	1,515.2 ± 4,172.04 (26.5)		696.33 ± 1.642.19 (22)		11.43 ± 21.77 (3)	
Score 5	27.25 ± 6.8 (28.5)		-		-	
Number of likes		6.121/0.190		3.699/0.296		1.387/0.500
Score 1	602.5 ± 955.02 (94.5)		13 ± 0 (13)		-	
Score 2	3,120.17 ± 9,025.55 (62)		18,412.76 ± 49,962.55 (245)		186.37 ± 312.68 (60)	
Score 3	2,279.4 ± 4,288.45 (357)		730.5 ± 1.141.07 (255)		105.33 ± 146.24 (48)	
Score 4	1,523.67 ± 2,195.97 (785)		93,504.67 ± 226,013.3 (603)		245.67 ± 331.3 (92)	
Score 5	798.75 ± 411.9 (747)		-		-	
Viewing rate		4.917/0.296		3.722/0.293		0.078/0.962
Score 1	267,709.9 ± 767,297.3 (39,862.44)		19,242.86 ± 0 (19,242.86)		-	
Score 2	1,814,908 ± 5,918,441 (27,175.76)		1,368,748 ± 2,150,512 (246,333.3)		85,577.97 ± 115,544.8 (21,925.09)	
Score 3	2,044,057 ± 4,160,927 (94,955.11)		3,017,986 ± 5,174.793 (668,070)		171,161.7 ± 318,336.8 (11,545.24)	
Score 4	4,918,599 ± 14,008,711 (157,787.1)		83,287,275 ± 196,000,000 (907,500)		20,204.25 ± 5,670.6 (19,473.08)	
Score 5	114,469.7 ± 49,763.08 (115,819.2)		-		-	

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Table 5. Continued

GQS score	YouTube	Test statistics/ p-value	TikTok	Test statistics/ p-value	Instagram	Test statistics/ p-value
Usefulness		43.379/<0.001*		14.150/0.003*		42.576/<0.001*
Score 1	3.44 ± 1.59 (4)		1 ± 0 (1)		-	30.387/<0.001*
Score 2	5.87 ± 1.84 (6)		3 ± 1.12 (3)		3.25 ± 0.8 (3)	
Score 3	8.9 ± 1.85 (9)		4.25 ± 1.26 (4)		5 ± 0.95 (5)	
Score 4	10.7 ± 2.75 (12)		5.83 ± 1.72 (5.5)		8.14 ± 1.21 (9)	
Score 5	13.25 ± 1.5 (14)		-		-	
DISCERN section 1		38.766/<0.001*		18.346/<0.001*		
Score 1	13.63 ± 4.01 (14)		8 ± 0 (8)			
Score 2	18.22 ± 3.26 (18)		15.53 ± 4.02 (14)		14.97 ± 2.02 (15)	
Score 3	24.3 ± 3.65 (23.5)		21 ± 2.45 (21.5)		17.48 ± 7.88 (20)	
Score 4	27.1 ± 7.67 (28.5)		28 ± 1.26 (28.5)		27.86 ± 2.04 (28)	
Score 5	37.5 ± 4.36 (39.5)		-		-	
DISCERN section 2		27.068/<0.001*		15.318/<0.001*		16.945/<0.001*
Score 1	13.25 ± 5.04 (11.5)		7 ± 0 (7)			
Score 2	14.74 ± 3.43 (15)		10.69 ± 2.24 (10.5)		9.94 ± 1.54 (10)	
Score 3	18.7 ± 3.68 (19)		14.25 ± 3.3 (13)		10.43 ± 3.34 (9)	
Score 4	22.9 ± 5.97 (25)		18.33 ± 4.18 (18)		17.43 ± 2.15 (17)	
Score 5	30 ± 7.57 (33)		-		-	
Total DISCERN		40.803/<0.001*		18.406/<0.001*		44.075/<0.001*
Score 1	26.87 ± 6.48 (27)		15 ± 0 (15)			
Score 2	33.39 ± 5.91 (33)		26.37 ± 5.39 (27.5)		24.91 ± 2.72 (24)	
Score 3	43 ± 6.43 (41)		35.25 ± 5.38 (34.5)		31.39 ± 3.92 (31)	
Score 4	50 ± 10.59 (50)		46.33 ± 5.16 (47)		45.29 ± 3.55 (45)	
Score 5	67.5 ± 11.9 (72.5)		-		-	

Values are presented as mean ± standard deviation (median).
GQS, Global Quality Scale.
YouTube: Google LLC, Mountain View, CA, USA. TikTok: ByteDance Ltd., Beijing, China. Instagram: Meta Platforms, Inc., Menlo Park, CA, USA.
*$p < 0.05$.

emotional and psychological effect, social media online video streaming services can be helpful in distance education [31]. Many educational videos can be found on YouTube, TikTok, and Instagram; however, some of them might contain inaccurate or out-of-date material because of variations in diagnosis and treatment methods [32,33]. No study has analyzed the quality of PT-related content on these three platforms together. Therefore, this article serves as a warning regarding the quality, accuracy, and reliability of information about PT disseminated on these platforms. We hypothesized that these videos tend to be unreliable and inaccurate and have poor educational quality due to their limited value.

Although numerous articles have explored YouTube content in a variety of dentistry- and medicine-related themes, few have examined TikTok and Instagram. Many studies exist in different fields of pediatric dentistry and endodontics addressing the YouTube platform [5,7,34], but only one has focused on the usefulness of videos on vital PT in endodontics, and no study exists on PT in pediatric dentistry [35]. Similarly, when the literature on both Instagram and TikTok videos is reviewed, very few studies exist on general and specialist dentistry topics [3,9,10], but one study has addressed these two social media platforms in pediatric dentistry [36]. Therefore, this study aimed to comprehensively evaluate videos on YouTube, TikTok, and Instagram by analyzing their content, quality, and reliability based on scores and statistical scales adapted from previous similar studies [3,9,34].

Video quality can be evaluated based on content topics; however, this approach may influence the data collected. Our literature review revealed that previous

Table 6. Distribution and comparison of video characteristics according to Usefulness scores

Usefulness score	Mean ± standard deviation (median)					
	YouTube	Test statistics/ *p*-value	TikTok	Test statistics/ *p*-value	Instagram	Test statistics/ *p*-value
Number of views		1.300/0.522		5.000/0.857		-
Low	259,634.72 ± 727,192.99 (6,766)		2,017,359.29 ± 8,827,612.77 (32,100)		4,758.28 ± 6,885.41 (1,508)	
Medium	922,471.2 ± 2,278,840.25 (24.378)		29,326.75 ± 33,688.52 (20.000)		3,571.67 ± 3,310.77 (2,138)	
High	48,903.92 ± 63,046.87 (30,932)		-		-	
Time since upload (mo)		1.048/0.592		5.500/0.857		0.000/>0.999
Low	56.56 ± 45.18 (41)		12.38 ± 11.93 (7)		12.08 ± 8.01 (11)	
Medium	50.36 ± 47.46 (40)		8 ± 5.35 (5.5)		11.85 ± 11.88 (9)	
High	46.92 ± 21.83 (39)		-		-	
Number of comments		0.756/0.685		5.000/0.857		0.500/>0.999
Low	124.68 ± 276.77 (6)		256.67 ± 839.05 (8.5)		6.08 ± 11.71 (1)	
Medium	789.72 ± 2,677.76 (3)		21.5 ± 36.64 (5)		12.62 ± 19.16 (4)	
High	21.92 ± 12.49 (21)		-		-	
Number of likes		2.956/0.228		4.000/0.643		0.000/>0.999
Low	1,178.92 ± 2,960.21 (113)		36,322.54 ± 118,301.69 (360.5)		157.02 ± 268.99 (57.5)	
Medium	3,474.04 ± 8,778.57 (357)		1,309.75 ± 2,310.08 (236.5)		186.73 ± 259.86 (87)	
High	635.08 ± 511.3 (530)		-		-	
Viewing rate		2.516/0.284		3.000/0.429		0.000/>0.999
Low	682,163.46 ± 2,265,045,13 (59,295.12)		22,225,090.3 ± 98,066,682.23 (305,000)		132,031.87 ± 249,945.54 (10,633.33)	
Medium	3,911,802.75 ± 10,296,877.01 (224,852.83)		420,347.5 ± 576,027.34 (195,125)		60,614.66 ± 99,050.87 (22,500)	
High	97,041.1 ± 80,519.3 (83,600)		-		-	
DISCERN section 1		33.073/<0.001*		0.000/0.071		0.000/>0.999
Low	15 ± 4.37 (15)		17.33 ± 5.77 (17)		15.37 ± 5.36 (15)	
Medium	20.96 ± 4.09 (21)		27 ± 2.83 (28)		24.85 ± 3.8 (25)	
High	30.92 ± 7.96 (31)		-		-	
DISCERN section 2		28.949/<0.001*				0.000/>0.999
Low	13.64 ± 5.09 (12)		11.96 ± 3.86 (12)	2.500/0.286	9.69 ± 1.47 (9)	
Medium	16.36 ± 3.73 (15)		17.5 ± 4.51 (16)		15.77 ± 4.04 (17)	
High	25.92 ± 5.53 (24)		-		-	
Total DISCERN		38.563/<0.001*		0.000/0.071		0.000/>0.999
Low	28.64 ± 7.68 (28)		29.48 ± 9.09 (28)		26.69 ± 3.47 (27)	
Medium	37.72 ± 5.92 (39)		44.5 ± 6.76 (44)		40.62 ± 6.92 (43)	
High	56.85 ± 12.17 (52)		-		-	

Values are presented as mean ± standard deviation (median).
YouTube: Google LLC, Mountain View, CA, USA. TikTok: ByteDance Ltd., Beijing, China. Instagram: Meta Platforms, Inc., Menlo Park, CA, USA.
*$p < 0.05$.

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studies have employed varying methods for selecting content topics, frequently utilizing questionnaires. In line with several other studies, we chose the closed-group discussion method to determine the content topics. Consultation was exclusively sought from qualified and experienced specialists in PT and dentistry active on social media platforms. Based on the recommendations of the American Association of Endodontists and the American Academy of Pediatric Dentistry, our research team conducted a comprehensive analysis of thematic elements and identified 15 topics [1,18,19].

PT-related YouTube, TikTok, and Instagram videos were evaluated in terms of usefulness, coverage, content, views, and likes in this study. The videos were assessed using the GQS, DISCERN, JAMA, and VIQI scales, commonly applied in previous research [21]. DISCERN plays a vital role in ensuring patient access to reliable healthcare information, enabling informed treatment decisions. VIQI assesses video content and information quality, while JAMA scores evaluate authorship, citation, annotation, and timeliness. GQS measures the quality, usability, and educational value of videos. Consistent with previous studies [37–39], GQS and DISCERN scores were used due to their reliability, while VIQI and JAMA further contributed to a comprehensive assessment [35,40]. Using all four scales in a single study enhances the depth of analysis.

YouTube, TikTok, and Instagram have distinct characteristics regarding content length, user demographics, and algorithmic structures [41]. Previous research in orthodontics [42] found similarities in video durations on YouTube and TikTok, whereas Bengi *et al.* [3] reported significant differences, with YouTube videos being significantly longer. Consistent with Bengi *et al.* [3], our study found YouTube videos to be nearly eight times longer than TikTok videos ($p > 0.001$). Most YouTube videos exceeded 45 seconds, while TikTok and Instagram videos ranged from 30 to 45 seconds due to platform limitations.

More accurate information can be obtained from sources such as healthcare professionals, hospitals, and academic institutions [3]. Paksoy *et al.* [9] reported that most of the videos regarding implant treatment on YouTube and TikTok were uploaded by healthcare professionals. Similarly, we found that most of the videos related to PT on YouTube (61.9%), TikTok (82.1%), and Instagram (75.8%) were uploaded by healthcare professionals ($p = 0.006$). Although it was not statistically significant, most of the videos were educational on all the social media platforms. Bengi *et al.* [3] reported that despite no statistically significant difference in usefulness score by the source of upload for YouTube videos, healthcare professionals uploaded statistically significantly more useful videos on TikTok. In the present study, the usefulness score on YouTube was higher than for Instagram or TikTok. Usefulness scores showed statistically significant differences between YouTube and Instagram and between YouTube and TikTok ($p < 0.05$).

Videos with rich content received more engagement in terms of likes, dislikes, and views compared to those with limited information ($p < 0.05$). This aligns with the expectation that high-quality content reaches a broader audience and ranks higher in search results. Additionally, content-rich videos garnered more appreciation from viewers. Many individuals rely on YouTube, TikTok, and Instagram for PT-related information. Patients share experiences to guide others in considering the procedure. McLean *et al.* [43] found that YouTube videos on root canal treatment received substantial engagement, with an average of 2,211 comments, 4,532.50 likes, and 1,037,189.10 views. Similarly, Bengi *et al.* [3] reported that YouTube videos on gingival enlargement had significantly higher engagement than TikTok videos. In our study, YouTube and TikTok videos had higher view, comment, and like counts than Instagram videos, indicating that these platforms reach a wider audience. Statistically significant differences in view rates were observed between TikTok and Instagram and between TikTok and YouTube ($p < 0.05$), with TikTok having the highest view rate.

Significant positive correlations were found between VIQI scores and usefulness, as well as DISCERN 1 and total DISCERN scores across all platforms ($p < 0.05$). This suggests that improving video information quality enhances reliability and patient utility, consistent with previous studies [35,44]. However, no significant association was observed between VIQI scores and DISCERN 2 scores on Instagram. JAMA criteria showed no significant correlation with any evaluation metric, aligning with Jung and Seo [45]. For Instagram videos, significant differences were found in JAMA scores based on the number of months since upload ($p < 0.05$). The majority of videos—73.1% on YouTube, 99% on TikTok, and 99% on Instagram—received low JAMA scores, indicating poor academic quality.

The correlation between video strength and usefulness, DISCERN sections 1 and 2, and total DISCERN scores was statistically significant and positive across YouTube, TikTok, and Instagram ($p < 0.05$). YouTube videos received the highest DISCERN and GQS scores, consistent with previous studies [46]. In line with Kılınç [42], who reported high-quality YouTube videos, our study found that YouTube content had superior educational value. Higher usefulness scores correlated with higher DISCERN measurements, further supporting the credibility of YouTube videos over other platforms.

This study has several limitations. First, its cross-sectional design and the analysis of only a subset of the available data may restrict the generalizability of the findings. Additionally, YouTube, TikTok, and Instagram are dynamic platforms, with search results varying over time due to changes in algorithms and user activity. Although we employed the most commonly used search terms, alterations to these terms or the timing of the search could yield different results. Consequently, many videos containing rich and relevant content may have been excluded. Furthermore, the study was restricted to English-language videos, limiting its applicability to non-English content.

CONCLUSIONS

The most notable finding of this study was that YouTube videos demonstrated greater reliability and accuracy compared to TikTok and Instagram, particularly regarding pulpotomy (PT) in both primary and permanent teeth. While the available content was generally useful for treatment-related information, there was a noticeable deficiency in topics related to etiology and prognosis. To address this gap, healthcare professionals should focus on creating high-quality, evidence-based educational content that covers not only treatment procedures but also underlying causes and long-term outcomes. YouTube should remain the primary platform for disseminating such content due to its higher reliability, but efforts to improve content quality on TikTok and Instagram should also be considered to reach a broader audience, including patients and general practitioners.

CONFLICT OF INTEREST

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

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AUTHOR CONTRIBUTIONS

Conceptualization, Methodology, Project administration, Validation: Güneç HG. Data curation: Okumuş DN, Erence MG. Formal analysis: Kaya E, Erence MG. Investigation: Güneç HG, Okumuş DN, Erence MG. Resources, Supervision, Visualization: Kaya E. Software: Erence MG. Writing - original draft: Güneç HG. Writing - review & editing: Kaya E. All authors read and approved the final manuscript.

DATA SHARING STATEMENT

The data used in this study are publicly available and do not involve any medical materials, images, or questionnaires. Data supporting the findings of this study are available at https://www.YouTube.com/, https://www.tiktok.com/ and https://www.instagram.com/ and in references [1–46].

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Is YouTube a reliable source for learning pre-endodontic build-up? A cross-sectional study

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ABSTRACT

Objectives: The aim of this study is to comprehensively analyze the quality, educational value, and demographic characteristics of pre-endodontic build-up videos published on the YouTube platform (Google LLC).
Methods: The study was conducted on YouTube using the keyword "pre-endodontic build-up." The first 100 videos retrieved from the search results were reviewed, and 61 videos meeting the inclusion criteria were analyzed. After assessing the demographic characteristics of the videos, viewing rates and interaction indices were calculated. The quality of the videos was evaluated using the DISCERN instrument and the Global Quality Scale (GQS). Statistical analyses were performed on the obtained results.
Results: A total of 61 videos were analyzed, of which 56% were uploaded by endodontists. The majority of the videos were found to be of low quality. As the DISCERN score increased, video duration, number of *likes*, number of comments, and view rate also increased. Additionally, a significant positive correlation was observed between the DISCERN score and the GQS value ($p = 0.004$). The relationship between video upload sources and various parameters was analyzed, revealing statistically significant differences ($p < 0.05$).
Conclusions: Considering all the evaluation methods used in this study, it is evident that the number of high-quality videos is low. This finding indicates that YouTube does not provide sufficient information on pre-endodontic build-up. To enhance its reliability as a source of medical information, YouTube should prioritize content that is not only popular but also accurate and of high quality, preferably created or endorsed by professionals.

Keywords: Education; Endodontics; Internet; YouTube

INTRODUCTION

In endodontic treatments, success rates have significantly improved. As a result, preserving natural dental tissue has become a primary focus. This paradigm shift has contributed to the progressive evolution of pre-end-

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odontic build-up procedures over the past century. These procedures have assumed an increasingly strategic role in dentistry. Their development has paralleled advancements in endodontic techniques and coronal restorative materials. Historically, pre-endodontic build-ups were not sufficiently evaluated for many years. This was despite their potential to prevent tooth fractures, strengthen weakened teeth, and improve treatment predictability. However, since the mid-20th century, these procedures have become more common in clinical practice. Notably, innovative developments in dental materials and adhesive techniques have significantly improved the durability and success of pre-endodontic build-ups [1,2].

A major advantage of pre-endodontic build-ups is the reinforcement of teeth with compromised structural integrity. Teeth requiring endodontic treatment often experience substantial structural loss due to factors such as decay, trauma, or previous restorations. A pre-endodontic build-up enhances the overall mechanical strength of the tooth by reconstructing the coronal region. This is achieved through the use of robust materials, thereby reducing the risk of fracture during or after the root canal treatment [2].

A pre-endodontic build-up restores the coronal structure of the tooth. This restoration improves access and visibility during root canal treatment [3]. As a result, it facilitates more effective cleaning, shaping, and obturation of the canals. When appropriately executed, pre-endodontic build-ups may contribute to improved predictability and treatment outcomes [4]. In cases of advanced structural compromise, pre-endodontic build-ups help prevent tooth extraction and support the preservation of natural dentition. These restorations also preserve masticatory function by maintaining occlusal integrity and interdental stability [5]. When modern aesthetic materials, such as shade-matched composite resins, are used, they can provide satisfactory esthetic outcomes [6].

A pre-endodontic build-up may be considered an essential component of the treatment strategy. It enhances the structural durability of the tooth and reduces the risk of fracture [1,2]. It also acts as a barrier against microorganisms, which reduces the risk of infection [7]. This barrier helps minimize microbial contamination and maintain coronal seal integrity. Together, these effects create an optimal environment for endodontic procedures [8]. As a result, the long-term prognosis of the treated tooth improves. This further supports the overall maintenance of oral health.

When appropriately performed, a pre-endodontic build-up may enhance the seal between the tooth surface and the rubber dam. This facilitates optimal isolation for endodontic procedures. By restoring coronal integrity and providing a stable platform, it allows rubber dam clamps to be securely positioned throughout treatment [8].

This study aims to evaluate the quality and educational value of YouTube (Google LLC, San Bruno, CA, USA) videos on pre-endodontic build-up. The alternative hypothesis is that the majority of these videos are of low educational quality or contain incomplete information.

With the widespread use of the internet and social media, individuals increasingly seek health-related information through online platforms [9]. YouTube, the second most visited website globally, provides easily accessible health-related content. However, it lacks peer-review mechanisms, which raises concerns regarding the reliability and accuracy of its content [10–12]. Although previous studies have assessed YouTube videos on various endodontic procedures [13–15], no study has systematically evaluated the quality and educational content of videos specifically focusing on pre-endodontic build-up to date. The present study aims to address this gap and represents a valuable addition to the current body of literature.

METHODS

This descriptive observational study was designed and reported in accordance with the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines. Since publicly available online data were used, ethical committee approval was not required.

Search strategy and keyword justification

To determine the most appropriate search term, a preliminary Google Trends analysis (2025, Alphabet Inc., USA) was conducted. Variants such as "pre-endodontic build-up," "preendo build up," and "pre endodontic

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buildup" were tested. Among these, "pre-endodontic build-up" showed the highest relevance and consistency. A supplementary search on YouTube confirmed substantial overlap in results across different phrasings. Therefore, "pre-endodontic build-up" was selected as the primary keyword.

The search was performed on January 22, 2025, on the YouTube platform (www.youtube.com) using Google Chrome (Google LLC, Mountain View, CA, USA) in incognito mode, with no user account logged in, in order to avoid algorithmic personalization. No filters or sorting options were manually applied; thus, videos were retrieved according to YouTube's default "relevance" ranking. To ensure traceability, all video URLs were backed up. As previous studies indicate that over 95% of users do not view results beyond the first five pages, the first 100 videos returned by the search were considered for analysis [16]. No videos featuring patients' or laypersons' personal experiences were encountered among the search results. All evaluated videos presented educational or procedural content related to pre-endodontic build-up.

Inclusion and evaluation

Videos that were not directly related to pre-endodontic build-up (n = 20, 20%), videos longer than 15 minutes (n = 3, 3%), duplicate videos (n = 10, 10%), non-English videos (n = 3, 3%), and videos with poor audiovisual quality (n = 3, 3%) were excluded from the study. A total of 61 videos met the inclusion criteria and were evaluated by a single endodontist (MG). Each video was scored using standardized instruments, and scores were systematically recorded. To assess intra-rater reliability, 20% of the videos (n = 12) were randomly selected and re-evaluated by the same endodontist (MG) after a one-week interval. Cohen's kappa values were calculated to assess intra-rater agreement.

The videos included in the study were evaluated based on the following parameters: video duration (in minutes), the time elapsed between the upload date and the current date (in days), the source of the video upload (endodontist, dentist, dental clinic, information website), number of views, number of comments, and the number of *likes* and *dislikes*. Since YouTube has restricted public access to *dislike* counts since 2021, these data were retrieved using the "Return YouTube Dislike" browser extension. This tool restores visibility based on the YouTube Data API and historical user feedback. *Dislike* counts were manually recorded during the data collection phase. The interaction index of the videos [(number of *likes* – number of *dislikes*) / number of views × 100] and the view rate (number of views/number of days since upload × 100) were calculated [12].

Scoring instruments

Two validated tools were used to assess educational quality and reliability (Table 1):

1. A five-question checklist adapted from the DISCERN instrument, scored as *Yes* = 1 and *No* = 0 (maximum score = 5) [17]
2. The Global Quality Scale (GQS), which uses a 5-point Likert scale ranging from 1 (poor) to 5 (excellent) [18]

Statistical analysis

Statistical analyses were performed using IBM SPSS version 30.0 (IBM Corp, Armonk, NY, USA). Normality was evaluated based on skewness and kurtosis values. Since the values were outside the acceptable range (± 1.5), nonparametric tests were applied. Descriptive statistics were presented as medians (range).

To compare continuous variables between groups, nonparametric tests, namely the Kruskal-Wallis H test and Mann-Whitney U test for pairwise comparisons, were employed. *Post-hoc* analyses were performed using Dunn test with Bonferroni correction to identify significant differences between different groups. In correlation analyses, Spearman rank correlation was used to examine the relationship between continuous variables. Statistical significance was set at $p < 0.05$.

Table 1. The modified DISCERN score (1 point for every yes, 0 points for *no*)

Item	Questions
1	Are the aims clear and achieved?
2	Are reliable sources of information used? (i.e., publication cited, speaker is specialist in diabetes)
3	Is the information presented both balanced and unbiased?
4	Are additional sources of information listed for patient reference?
5	Are areas of uncertainty mentioned?

RESULTS

In accordance with the exclusion criteria, 61 YouTube videos were included in the final analysis. The majority (56%) of the videos were uploaded by endodontists (n = 34), followed by information websites (23%, n = 14), dentists (15%, n = 9), and dental clinics (6%, n = 4). Table 2 presents descriptive statistics including the number of views, video duration (in seconds), number of *likes*, number of *dislikes*, number of comments, GQS score, DISCERN score, video timespan (in days), interaction index, and view rate. Data are presented as mean ± standard deviation and median (range). Intra-rater reliability was calculated to assess rating consistency and revealed substantial agreement for both evaluation tools (κ = 0.64 for GQS; κ = 0.63 for the DISCERN checklist).

Regarding overall quality, most of the videos were rated as low quality based on the GQS. Specifically, 16.4% (n = 10) of the videos were assigned a GQS score of 1, and 39.3% (n = 24) received a score of 2. No video received the maximum GQS score of 5, which represents excellent quality and flow (Table 3).

As shown in Table 4, statistically significant differences were observed between video upload sources in terms of several variables ($p < 0.05$). These included the number of views, video duration, number of *likes*, number of comments, interaction index, and view rate. Videos uploaded by information websites had the highest median view count and duration. In contrast, videos uploaded by endodontists had the lowest view count but demonstrated the highest interaction index.

Videos with a DISCERN score of 1–3 had significantly more views than those with a score of 0 (p = 0.019). Sim-

Table 2. Descriptive statistics of video viewership, duration, engagement, and quality parameters

Parameter	Mean ± standard deviation	Median (range)
View	4,664.41 ± 7,925.93	1,500 (24–38,000)
Duration (sec)	189.46 ± 169.50	136 (30–1,010)
Like	55.90 ± 84.65	18 (0–424)
Dislike	1.79 ± 5.04	0 (0–30)
Comment	4.70 ± 6.57	2 (0–25)
Global Quality Scale	2.43 ± 0.94	2 (1–4)
Video timespan (day)	2,041.30 ± 1,270.92	1,826 (210–4,745)
DISCERN	0.59 ± 0.82	0 (0–3)
Interaction index	1.58 ± 1.19	1.5 (0–8.33)
View rate	265.68 ± 390.59	98.57 (5.75–1,643)

Table 3. Distribution of videos based on quality levels

Global Quality Scale	*n* (%)
1. Poor quality, poor flow of the video, most information missing, not at all useful for patients	10 (16.4)
2. Poor quality, poor flow of the video, most information missing, not at all useful for patients	24 (39.3)
3. Moderate quality, suboptimal flow, some important information is adequately discussed but others poorly discussed, somewhat useful for patients	18 (29.5)
4. Good quality and generally good flow. Most of the relevant information is listed, but some topics are not covered, useful for patients	9 (14.8)
5. Excellent quality and flow; very useful for patients	
Total	61 (100)

Table 4. Analysis of variables based on the video uploader

Variable	Dentist	Information websites	Endodontist	Dental clinic	H	*p*-value
View	797 (24–14,000)[a]	7,254 (810–38,000)[b]	903.5 (140–6,400)[a]	7,000 (1,200–28,000)[ab]	18.219	<0.001*
Duration (sec)	136 (30–557)[a]	307.50 (78–1,010)[b]	89 (58–649)[a]	154 (99–245)[ab]	19.222	<0.001*
Like	4 (0–424)[a]	70 (4–239)[b]	18 (0–100)[ab]	120.5 (4–262)[ab]	10.661	0.014*
Dislike	0 (0–3)	0 (0–20)	(0–9)	(0–30)	2.437	0.487
Comment	1 (0–18)[a]	7 (0–24)[b]	1.5 (0–12)[a]	9.5 (0–25)[ab]	14.575	0.002*
Video timespan (day)	1,826 (335–4,380)	2557 (365–4,745)	1,826 (210–4,745)	3,832.5 (730–4,745)	7.747	0.052
Interaction index	1.14 (0–8.33)[ab]	1.02 (0.36–2.59)[a]	1.63 (0–3.4)[b]	0.66 (0.2–1.95)[ab]	8.159	0.043*
View rate	109.17 (5.75–547.51)[ab]	424.65 (23.18–1,486)[a]	49.48 (12.78–1,571)[b]	500.52 (25.28–1,643)[ab]	9.941	0.019*

Values are presented as median (range).
The superscript letters represent the post-hoc results. Differences between different letters are significant.
Kruskal-Wallis H Test; *$p < 0.05$.

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ilarly, as the DISCERN score increased, video duration, number of *likes*, number of comments, and view rate also increased. This difference was found to be statistically significant ($p < 0.05$) (Table 5).

When evaluating DISCERN and GQS, dentists, information websites, and dental clinics were grouped together and compared with endodontists. While there was no statistically significant difference between the two groups in terms of GQS ($p > 0.05$), DISCERN scores were significantly lower for videos uploaded by endodontists ($p = 0.002$) (Table 6).

Spearman correlation analysis revealed strong positive correlations between the number of video views and the following variables: video duration (r = 0.525, $p < 0.001$), number of *likes* (r = 0.847, $p < 0.001$), number of comments (r = 0.714, $p < 0.001$), and view rate (r = 0.846, $p < 0.001$) (Table 7). These relationships are illustrated in Figure 1, which shows the distribution of videos by the number of views and *likes*. Each point in the plot represents one video, and a clear trend is observable, indicating that videos with more views tend to receive more *likes* (r = 0.847). Moreover, the number of *likes* demonstrated a positive association with the number of comments, as well as with both GQS and DISCERN scores. A statistically significant correlation was also observed between GQS and DISCERN scores (r = 0.435, $p < 0.001$).

DISCUSSION

The findings highlight the volume of existing informational content on YouTube regarding pre-endodontic build-up. In endodontic treatment processes, patient cooperation and a high level of knowledge about the procedure are of critical importance. YouTube videos may serve an educational role for both patients and clinical professionals. They can enhance confidence, support knowledge acquisition, and improve procedural understanding [19,20]. YouTube is one of the largest and most widely used video-sharing platforms globally. It offers free access and hosts a vast array of health-related educational content. However, the lack of robust content moderation mechanisms increases the risk of videos containing inaccurate or incomplete information [21]. This creates a paradox in which widely accessed content may not meet the quality standards required for clinical or educational reliability.

A study comparing video-based and traditional learning among first-year dental students found video-based learning significantly more effective [22]. Another study, conducted on 479 dentistry students, examined the effectiveness of YouTube in learning clinical procedures. The findings revealed that 95% of the students perceived the videos as beneficial. However, 36% of the participants expressed concerns regarding the accuracy

Table 6. Analysis of quality parameters of videos uploaded by endodontists and other groups

Parameter	Endodontist	Others	*U*	*p*-value
Global Quality Scale	2 (1–4)	3 (1–4)	0.610	0.542
DISCERN	0 (0–3)	1 (0–3)	3.090	0.002*

Values are presented as median (range).
Mann-Whitney *U* Test; *$p < 0.05$.

Table 5. Comparison of video characteristics based on DISCERN score

Variable	DISCERN		*U*	*p*-value
	0	1–3		
View	975 (141–12,000)	3,629.5 (24–38,000)	2.341	0.019*
Duration (sec)	90 (30–1,010)	241 (48–649)	3.326	<0.001*
Like	18 (0–200)	36 (0–424)	1.970	0.049*
Dislike	0 (0–9)	0 (0–30)	1.129	0.259
Comment	1 (0–24)	4.5 (0–25)	2.547	0.011*
Global Quality Scale	2 (1–4)	3 (1–4)	2.896	0.004*
Video timespan (day)	1,826 (730–4,745)	1,826 (210–4,745)	0.438	0.662
Interaction index	1.56 (0–3.4)	1.32 (0–8.33)	1.036	0.300
View rate	45.56 (19.31–780.82)	376.71 (5.75–1,643)	2.888	0.004*

Values are presented as median (range).
Mann-Whitney *U* test; *$p < 0.05$.

Table 7. Correlation analysis between parameters

Parameter	View	Duration (sec)	*Like*	*Dislike*	Comment	GQS	Video timespan (day)	DISCERN	Interaction index	View rate
View										
r	1.000	0.525**	0.847**	0.460**	0.714**	0.268*	0.333**	0.299*	−0.286*	0.846**
p-value	–	<0.001	<0.001	<0.001	<0.001	0.037	0.009	0.019	0.025	<0.001
Number	61	61	61	61	61	61	61	61	61	61
Duration (sec)										
r	0.525**	1.000	0.459**	0.267*	0.460**	0.417**	0.170	0.443**	−0.159	0.431**
p-value	<0.001	–	<0.001	0.038	<0.001	<0.001	0.190	<0.001	0.222	<0.001
Number	61	61	61	61	61	61	61	61	61	61
Like										
r	0.847**	0.459**	1.000	0.534**	0.793**	0.300**	0.132	0.253*	0.158	0.811**
p-value	<0.001	<0.001	–	<0.001	<0.001	0.004	0.309	0.049	0.225	<0.001
Number	61	61	61	61	61	61	61	61	61	61
Dislike										
r	0.460**	0.267*	0.534**	1.000	0.488**	0.130	0.244	0.120	−0.088	0.397**
p-value	<0.001	0.038	<0.001	–	<0.001	0.319	0.058	0.358	0.501	0.002
Number	61	61	61	61	61	61	61	61	61	61
Comment										
r	0.714**	0.460**	0.793**	0.488**	1.000	0.289*	−0.006	0.340**	0.030	0.768**
p-value	<0.001	<0.001	<0.001	<0.001	–	0.024	0.964	0.007	0.820	<0.001
Number	61	61	61	61	61	61	61	61	61	61
GQS										
r	0.268*	0.417**	0.359**	0.130	0.289*	1.000	0.137	0.435**	0.159	0.193
p-value	0.037	<0.001	0.004	0.319	0.024	–	0.293	<0.001	0.221	0.137
Number	61	61	61	61	61	61	61	61	61	61
Video timespan (day)										
r	0.333**	0.170	0.132	0.244	−0.006	0.137	1.000	−0.066	−0.386**	−0.131
p-value	0.009	0.190	0.309	0.058	0.964	0.293	–	0.611	0.002	0.313
Number	61	61	61	61	61	61	61	61	61	61
DISCERN										
r	0.299*	0.443**	0.253*	0.120	0.340**	0.435**	−0.066	1.000	−0.091	0.362**
p-value	0.019	<0.001	0.049	0.358	0.007	<0.001	0.611	–	0.484	0.004
Number	61	61	61	61	61	61	61	61	61	61
Interaction index										
r	−0.286*	−0.159	0.158	−0.088	0.030	0.159	−0.386**	−0.091	1.000	−0.125
p-value	0.025	0.222	0.225	0.501	0.820	0.221	0.002	0.484	–	0.336
Number	61	61	61	61	61	61	61	61	61	61
View rate										
r	0.846**	0.431**	0.811**	0.397**	0.768**	0.193	−0.131	0.362**	−0.125	1.000
p-value	<0.001	<0.001	<0.001	0.002	<0.001	0.137	0.313	0.004	0.336	–
Number	61	61	61	61	61	61	61	61	61	61

*$p < 0.05$, **$p < 0.01$.

of the content presented in the videos. Among dentistry students, YouTube is frequently used for learning clinical procedure techniques and for better visualizing and understanding abstract concepts [23]. While some studies highlight the educational value of YouTube, Cuddy [24] argued that many videos may have been uploaded primarily to serve the commercial interests of their creators rather than to provide educational content. This contrast between perceived usefulness and concerns over accuracy underscores the need for critical evaluation of video-based learning tools.

Desai *et al.* [25] have stated that 95% of individuals

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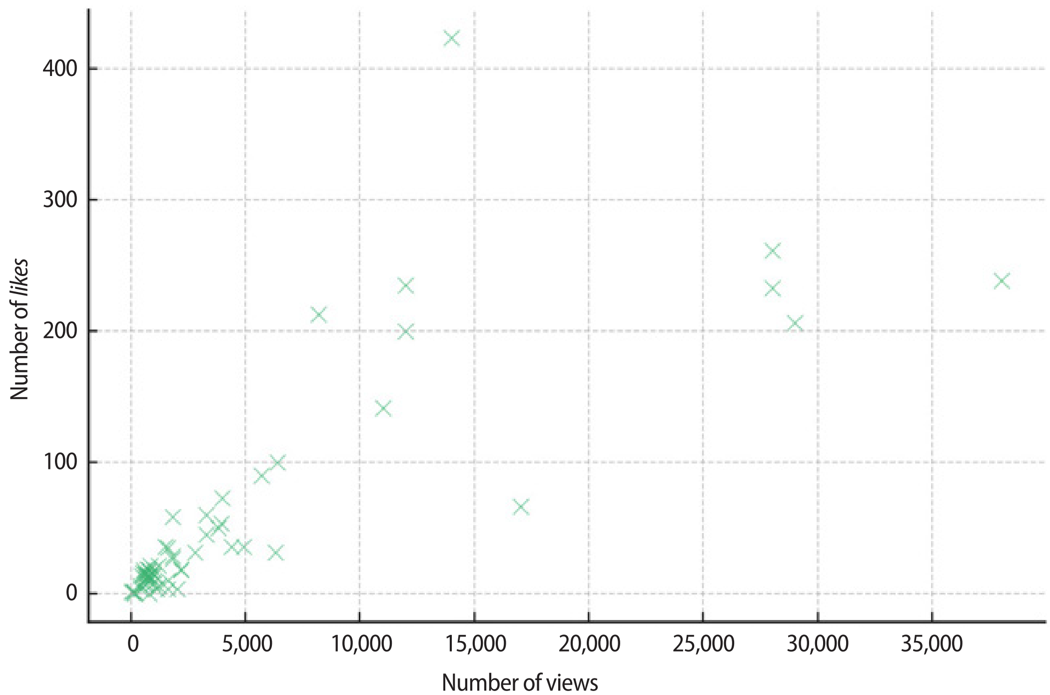

Figure 1. Scatter plot demonstrating the positive correlation between video views and likes.

conducting online searches examine only the first three pages of search results [25]. This reflects the typical search behavior of internet users. Most people tend to limit their exploration to the first 50 results and do not review additional content [26]. Therefore, in the present study, only the first 100 videos were analyzed. Further examination of additional videos was not pursued, as their contribution was considered likely limited. However, this approach may also limit the inclusion of less visible but potentially higher-quality content that exists beyond the initial search results. The exclusion of videos longer than 15 minutes is based on previous research. These studies suggest that longer videos are less likely to maintain viewers' attention and therefore receive fewer views [16,19]. Additionally, YouTube users spend an average of 40 minutes per day on the platform. Given that audience engagement rates range between 50% and 60%, shorter videos are anticipated to be more effective [27].

Several studies in the literature have observed that the proportion of videos uploaded by dentists exceeds 40% [28,29]. For instance, in a 2023 study on bruxism conducted by Alkan Aygör and Ekrikaya [30], it was found that 78% of the analyzed videos were uploaded by dentists. This phenomenon may be attributed to several factors. These include the subject matter under investigation, the nature of the videos produced, and the inclusion and exclusion criteria applied by researchers. Similarly, in the present study, 43 out of 61 videos were uploaded by healthcare professionals (dentists or endodontists), accounting for 70.4% of the sample. Given the specialized nature of the topic, it is reasonable that a significant proportion of the videos were shared by healthcare professionals. A study by Cokakoglu and Cakir [31] on digital indirect orthodontic bracket bonding, which focused on a professional subject, observed that all the analyzed videos were uploaded by dental companies and dentists. This suggests that the more specialized the topic, the more likely it is that content will be uploaded by professionals. In contrast, Yavuz *et al.* [32] reported that only 32.5% of the videos they examined on the topic of "orthodontics" were uploaded by dentists. This supports the notion that topic specificity and technical depth may influence the professional composition of video content on YouTube.

Özdal Zincir *et al.* [33] investigated the impact of videos related to surgical third molar extraction on potential patient education. Similar to the findings of the present study, their research identified a significant relationship between the source of video uploads and the demographic characteristics of the videos. Erturk-Avunduk and Delikan [34] reported that videos uploaded by dentists had higher view rates compared to those uploaded by other sources. These findings indicate that videos shared by healthcare professionals may attract greater interest. However, this observation differs from the results of the current study. According to the present study, videos uploaded by endodontists had the lowest view rates, followed by those uploaded by dentists. It is possible that endodontists, although highly skilled clinically, may prioritize procedural demonstration over patient-oriented explanation. This approach may result in lower performance in categories such as balance, references, or clarity. Nason *et al.* [19] in their study analyzing YouTube videos on root canal treatment, found that DISCERN scores varied among videos uploaded by clinicians and unknown sources. Meanwhile, content produced by non-clinicians exhibited significantly lower reliability performance. This finding is not consistent with the current study. In our sample, videos uploaded by information websites and dental clinics received higher DISCERN scores compared to those uploaded by dentists and endodontists. This inconsistency may be explained by differences in video selection criteria, language, or evaluation tools used in previous studies. In a study conducted by Meriç [35] on Turkish-language YouTube videos about fissure sealants, no statistically significant relationship was found between the source of video uploads and the usefulness of the videos. Similarly, our findings revealed no significant association between the video source and GQS scores. However, a significant relationship was observed between the video source and DISCERN scores.

Numerous studies have evaluated the quality of information available on YouTube regarding various topics from a patient perspective using the GQS [17,29]. The scoring criteria of this scale are specifically designed to assess information quality from the perspective of patients. Erturk-Avunduk and Delikan [34] concluded that videos uploaded by sources other than dentists and specialists contained less informative content. Among the analyzed English-language videos, 48.2% received a score of 2 on the GQS, classifying them as low quality. In the present study, this rate was found to be 39.3%. Consistent with the findings of Erturk-Avunduk and Delikan [34], none of the analyzed videos received a score of 5 on the GQS index. This may be attributed to several content-related shortcomings. These include a lack of structured content delivery, insufficient explanation of clinical rationale, or limited use of educational visuals—all of which are emphasized in the original GQS framework [18]. These consistent outcomes across different studies may reflect broader challenges in producing pedagogically effective YouTube content, particularly in dental education.

Meriç [35] reported that no statistically significant relationship was found between the number of views, view rate, interaction index, and usefulness score [35]. In contrast, Erturk-Avunduk and Delikan [34] identified a positive correlation between the interaction index and video duration. Yavuz *et al.* [32] noted that shorter videos had higher view rates. Similarly, the findings of the present study indicate several strong positive correlations. These include associations between the number of video views and video duration, number of *likes*, number of comments, and view rate. Additionally, Erturk-Avunduk and Delikan [34] identified a negative correlation between the interaction index and the upload date of the videos. This observation contradicts the perspective of Nason *et al.* [19], who suggested that videos uploaded in earlier periods should have higher view counts. Such inconsistencies may stem from variations in sampling periods, video topics, or evolving viewer behaviors over time.

YouTube search results are ranked not based on the quality or informational accuracy of the videos. Instead, they are determined by relevance to the searched keywords, user engagement, popularity, and previous view counts. This ranking mechanism may facilitate the rapid dissemination of misinformation. Although YouTube encourages users to create content and enforces community guidelines, its business model imposes minimal restrictions on video production. The platform also fosters a highly competitive environment by emphasizing performance metrics such as subscriber count, views, and watch time. However, since this competitive structure does not account for content quality, low-quality videos may achieve high view counts, while high-quality

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videos may remain under-watched. A study conducted by Qi *et al.* [36] reported that YouTube videos containing both appropriate and inappropriate content regarding psoriasis had comparable view counts. Similarly, a study by Osman *et al.* [37] concluded that YouTube is not a reliable source of information on health-related topics.

One limitation of this study is the absence of an established standardization for the analysis of video-based resources. In this context, the researchers conducted a comprehensive literature review to develop a checklist. The videos were then evaluated subjectively, as commonly applied in other studies within the field of dentistry [11,19]. Another limitation is that, despite the global prevalence of root canal treatment, only videos in English were analyzed. Since English is not the primary language in many countries, this constraint may limit the generalizability of the findings. An additional limitation is the time-dependent nature of the results, due to YouTube's dynamic and continuously evolving platform. Videos are regularly uploaded and removed. As a result, the reproducibility of this study cannot be guaranteed, and the available content will inevitably change over time. Another limitation is that all video assessments were conducted by a single evaluator. Although intra-rater reliability was calculated and found to be substantial, the lack of inter-rater evaluation may limit the generalizability and validity of the findings. Despite these limitations, the study provides insights into the current landscape of online educational content on pre-endodontic build-up. It also highlights the need for more standardized evaluation frameworks.

CONCLUSIONS

The present study found that 55.7% of YouTube videos addressing the topic of pre-endodontic build-up were of low educational quality, as reflected by GQS scores of 1 or 2. Furthermore, although endodontists constituted the majority of content uploaders (56%), videos from this group demonstrated significantly lower DISCERN scores than those uploaded by other sources ($p = 0.002$). These findings indicate a limited presence of high quality, reliable educational content on this specific topic within the YouTube platform. To improve the overall quality and reliability of such content, future content production should be supported by academic collaboration and standardized evaluation criteria.

CONFLICT OF INTEREST

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

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AUTHOR CONTRIBUTIONS

Conceptualization, Investigation, Methodology, Visualization: Gökyar M. Data curation, Validation: Özden İ. Formal analysis, Project administration, Supervision: Öveçoğlu SH. Writing - original draft: Özden İ. Writing - review & editing: Gökyar M. All authors read and approved the final manuscript.

DATA SHARING STATEMENT

The datasets are not publicly available but are available from the corresponding author upon reasonable request.

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Isolating design variables by assessing the impact of cross-section geometry on the mechanical performance of nickel-titanium rotary instruments: a comparative *in vitro* study

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ABSTRACT

Objectives: This study aimed to assess the effect of cross-section geometry on the mechanical properties of nickel-titanium (NiTi) instruments by comparing two instruments with identical tip size, taper, and thermal treatment but differing in cross-section design.
Methods: One hundred four NiTi rotary instruments, being S-shaped and triangular cross-section, manufactured with Blueish thermal treatment, were tested ($n = 52$ per group). Differential scanning calorimetry was employed, and the metal mass volume and cross-section area were assessed. The cyclic fatigue, torsional, and bending resistance tests were assessed. Data were analyzed using the Kolmogorov-Smirnov and Student *t*-tests, and the level of significance was set at 5%.
Results: The instruments exhibited similar start and finish temperatures of phase transformation. The S-shaped instruments had significantly lower metal mass volume and cross-sectional area ($p < 0.05$). S-shaped instruments demonstrated superior cyclic fatigue resistance, greater angular deflection, and lower bending stiffness ($p < 0.05$).
Conclusions: Cross-section geometry significantly influences the mechanical properties of NiTi rotary instruments.

Keywords: Endodontics; Fatigue; Mechanical tests; Nitinol

INTRODUCTION

The introduction of nickel-titanium (NiTi) rotary instruments has transformed endodontic practice, improving the efficiency and predictability of root canal shaping while reducing the risk of procedural errors [1]. Com-

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pared to stainless-steel instruments, NiTi files exhibit superior flexibility, allowing for better canal centering and adaptation to complex root anatomies [2,3]. Furthermore, NiTi instruments combine optimal cutting efficiency and enhanced cyclic fatigue resistance, resulting in both safer and more effective root canal preparations [4,5]. However, despite these advancements, NiTi instruments remain susceptible to mechanical failure, particularly in anatomically complex canals where increased torsional stress and cyclic fatigue can lead to fracture [3]. Instrument separation during treatment disrupts root canal debridement and disinfection, potentially compromising overall treatment outcomes [6].

Given the risk of mechanical failure, ongoing research has focused on optimizing the design and metallurgical properties of endodontic instruments to enhance both performance and safety [3]. Manufacturers have introduced several modifications, including variations in cross-section geometry, pitch number, core diameter, taper, and thermal treatment of the NiTi alloy [3,5,7]. Among these factors, cross-section geometry plays a critical role in determining mechanical behavior. However, its specific influence remains underexplored, particularly in studies with well-controlled and methodologically sound designs. Along with tip design and taper, cross-section geometry significantly affects instrument stiffness by determining metal mass distribution, polar moment of inertia, and overall resistance to deformation [7,8]. In turn, stiffness is a key determinant of clinical performance, influencing cutting efficiency, stress distribution along the instrument, and shaping ability within the root canal system [3,5,7,8]. Given these considerations, clinicians must critically evaluate how different design features influence instrument performance to optimize their selection based on specific clinical needs [3,7].

Studies using finite element analysis suggest that triangular-based cross-sections, such as convex and triple-helix designs, may promote better stress distribution and lower stress concentration compared to S-shaped cross-sections [9–11]. This characteristic is supposedly associated with improved safety of NiTi instruments during root canal preparation, particularly in curved canals [10]. Conversely, other laboratory studies have reported that S-shaped cross-sections provide greater flexibility [12,13], improved flexural properties, and better centering ability compared to triangular-based designs [14,15]. These conflicting findings may stem from variations in experimental methodologies and differences in additional design features among commercially available NiTi instruments. Furthermore, finite element analysis has inherent limitations, as its accuracy depends on the material properties assigned to the virtual model and often fails to account for clinically relevant factors such as surface finish, microdefects, and manufacturing inconsistencies [16].

Understanding the influence of cross-section geometry on the mechanical properties of NiTi rotary instruments is essential for optimizing their clinical performance and ensuring predictable outcomes. To accurately assess this impact, cross-section geometry must be isolated as the only variable, ensuring that differences in mechanical behavior are not confounded by factors such as tip size, taper, or thermal treatment. Therefore, this study aimed to evaluate the influence of cross-section geometry on the mechanical properties of NiTi instruments by comparing two instruments with identical tip size, taper, and thermal treatment but differing in cross-section design. The null hypothesis states that cross-section geometry has no significant effect on the cyclic fatigue resistance, torsional resistance, or bending properties of the tested instruments.

METHODS

Sample size calculation and sample selection

Sample size calculation was performed using G*Power v3.1 software (Heinrich Heine University of Düsseldorf, Düsseldorf, Germany). The sample size estimation was based on preliminary results obtained from five initial tests. An alpha error of 0.05 and a statistical power of 80% were considered. The effect sizes used were: 11.1 for time to fracture, 4.4 for maximum torque, 6.9 for maximum rotation angle, and 1.9 for bending strength. The required sample sizes were determined as 2, 3, 3, and 6, respectively. To ensure robust statistical analysis, a final sample size of 10 instruments per group was selected.

A total of 104 rotary NiTi instruments (n = 52 per group) with either an S-shaped or triangular cross-section were selected for analysis. All instruments had a tip

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size of 25, a 0.06 taper, and a length of 25 mm. They were manufactured using Blueish thermal treatment (Mk Life Medical and Dental Products, Porto Alegre, Brazil) and evaluated for their mechanical properties and metallurgical characteristics. Prior to testing, all instruments underwent microscopic inspection at 16× magnification with LED illumination (Carl Zeiss Microscopy, LLC, White Plains, NY, USA) to identify any significant defects, such as blade design irregularities or unwinding, that could disqualify them from the study. No defects were found, and all instruments were deemed suitable for inclusion.

Design assessment

Six instruments from each group were randomly selected for examination under a stereomicroscope (Opmi Pico, Carl Zeiss Surgical, Jena, Germany) using ImageJ software (ver. 1.50e; Laboratory of Optical and Computational Instrumentation, Madison, WI, USA) at 13.6× magnification [17]. The images were analyzed to assess the length of the active cutting blade, number of spirals, spirals per millimeter, and spiral direction. For illustrative purposes, the instruments were also photographed using a digital camera (Canon EOS 500D; Canon, Tokyo, Japan) paired with a 1:1 Macro Lens (IRIX 150 mm F/2.8; TH Swiss, Baar, Switzerland) to ensure high-resolution images with minimal distortion (Figure 1).

Differential scanning calorimetry

Differential scanning calorimetry (DSC) tests were performed to assess the phase transformation temperatures of the tested instruments, following the protocol described by Teves Cordova *et al.* [18]. This standardized approach ensures reliable measurement of phase transitions by monitoring heat flow variations as a function

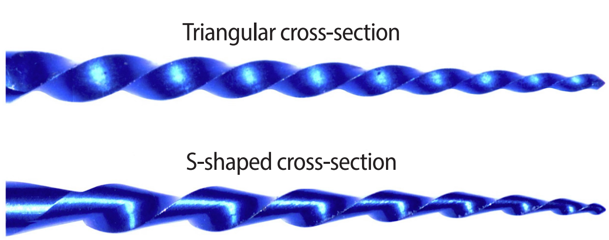

Figure 1. Macroscopic images of the instruments tested with triangular cross-section (top) and S-shaped cross-section (bottom).

of temperature. Small fragments (3–5 mm in length, 7–12 mg in weight) were sectioned from the active blade of each instrument (n = 6 per group) and etched in a solution of 25% hydrofluoric acid, 45% nitric acid, and 30% distilled water for 2 minutes. After rinsing with distilled water, the specimens were placed in aluminum pans, with an empty pan serving as a control. The heat cycle lasted 45 minutes and consisted of the following stages:

- Isothermal hold at 25°C for 5 minutes;
- Heating to 150°C at a rate of 10°C/min, followed by a 2-minute isothermal hold;
- Cooling to –30°C at 10°C/min, followed by another 2-minute isothermal hold;
- Reheating to 150°C at 10°C/min, with a final 2-minute isothermal hold;
- Final cooling to 25°C.

DSC analyses were conducted using the DSC Stare 1 system (DSC 204 F1 Phoenix; Netzsch-Gerätebau GmbH, Selb, Germany). The resulting phase transformation temperatures were processed with Netzsch Proteus Thermal Analysis software (Netzsch-Gerätebau GmbH). To ensure reproducibility, each test was performed twice per group, and results were compared for consistency.

Metal mass volume and cross-sectional area analysis

Twenty rotary NiTi instruments (n = 10 per group) with either an S-shaped or triangular cross-section were analyzed. Metal mass volume (mm^3) and cross-sectional area (μm^2) were assessed using micro-computed tomography (micro-CT) (Skyscan 1174v2; Bruker Belgium N.V., Kontich, Belgium), following a previously described methodology [19]. Micro-CT imaging was performed using the following parameters: 50 kV, 800 μA, 360° rotation, isotropic resolution of 14.1 μm, and a 0.5 mm-thick aluminum filter. The acquired images were reconstructed into cross-sectional slices perpendicular to the instrument's long axis using dedicated software (NRecon ver. 1.6.3, Bruker Belgium N.V.), allowing both two-dimensional (2D) and three-dimensional (3D) analyses. In the 3D analysis, metal mass volume was measured from the instrument tip to the 3rd and 5th mm (Figure 2A). For 2D analysis, reconstructed cross-section slices provided a topographic view at 3 and 5 mm from the tip, where the cross-section area (μm^2) was quantified for comparison (Figure 2B).

Mechanical tests

Cyclic fatigue test was performed at body temperature (35°C ± 1°C) [19]. To maintain stable thermal conditions, the cyclic fatigue device was submerged in a histology water bath (Leica HI1210; Leica Biosystems, Milton Keynes, UK) filled with distilled water, with continuous temperature monitoring. The instruments were mounted on a 6:1 reduction handpiece (Sirona Dental Systems GmbH, Bensheim, Germany) and driven by a torque-controlled motor set to the RECIPROC ALL mode (VDW Silver; VDW GmbH, Munich, Germany). Instruments operated at 400 revolutions per minute (RPM) with a torque of 2 N•cm and were tested in a static position within an artificial stainless-steel canal with a 5-mm radius and a 60° curvature [19]. Fracture occurrence was identified through visual and auditory cues, and the time to fracture (in seconds) was recorded using a digital chronometer. The number of cycles to failure (NCF) was calculated as: NCF = (time to failure in seconds × RPM) / 60.

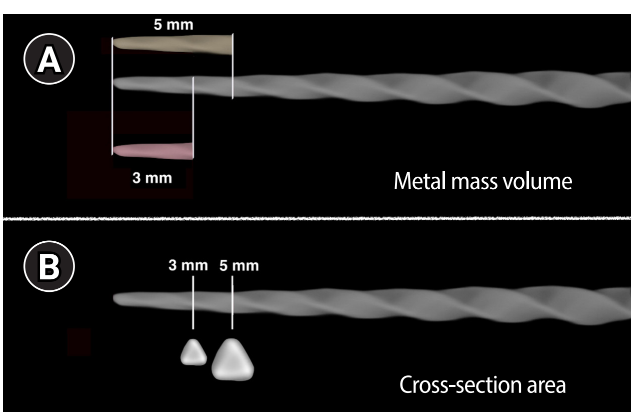

Figure 2. Representative images of micro-computed tomography analysis of metal mass volume and cross-section area. (A) The metal mass volume from the instrument tip to the 3 and 5 mm from the tip of the instrument. (B) The cross-section area was measured using the cross-section slices at 3 and 5 mm from the tip of the instrument.

Torsional strength (n = 10), assessed by measuring maximum torque (N•cm) and angle of rotation (°), along with bending resistance (n = 10), determined by maximum bending load (gf), were evaluated according to an international standard (ISO 3630-3631, 2008) and as previously reported [18,19].

Scanning electron microscopy

Fractured fragments from both cyclic fatigue and torsional tests were examined using scanning electron microscopy (SEM) (JSM-TLLOA; JEOL, Tokyo, Japan) to analyze the topographic features of the fracture surfaces. Images were acquired at 150× and 1,000× magnifications to assess characteristic failure patterns.

Statistical analysis

The evaluation of instrument design parameters, such as the number of blades and helical angle, was purely descriptive and therefore not subjected to statistical analysis. Similarly, the DSC analysis aimed to verify consistency in phase transformation temperatures (austenite start temperature [As] and austenite finish temperature [Af]) across the instruments treated with the Blueish thermal process, and as such, did not require inferential statistical testing.

The normality of the data from the mechanical tests (cyclic fatigue, torsional resistance, and bending), as well as the metal mass volume and cross-sectional area measurements, was confirmed using the Shapiro-Wilk test. Group comparisons were then performed using an independent Student t-test, with a significance level set at 5% (IBM SPSS ver. 22.0 for Windows; IBM Corp, Armonk, NY, USA).

RESULTS

Design assessment

The geometric design characteristics of the tested instruments are illustrated in Figure 1 and summarized in Table 1. The active blade length remained consistent at

Table 1. Geometric design characteristics of the assessed instruments

Instrument	Size/taper	Active blade length (mm)	Number of spirals	Spirals/mm	Helical angle (º)
S-Shaped	25/0.06	16	8	0.50	35.1
Triangular	25/0.06	16	9	0.56	25.4

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16 mm for both cross-section designs. Variations were observed in the number of spirals, with the S-shaped cross-section presenting eight spirals and the triangular cross-section exhibiting nine spirals. When adjusted for length, the number of spirals per millimeter was 0.56 for the S-shaped cross-section and 0.50 for the triangular cross-section. Additionally, the helical angle differed considerably between the groups, with the S-shaped cross-section displaying the highest mean helical angle (35.1°), while the triangular cross-section had the lowest mean helical angle (25.4°).

Differential scanning calorimetry analysis

The DSC analysis determined the As and Af temperatures of both tested instruments, representing the start (As) and finish (Af) points of the austenitic phase transformation. Both instruments exhibited comparable transformation temperatures, indicating similar thermal behavior under the Blueish thermal treatment. The S-shaped cross-section instruments had an As of 37.2°C and an Af of 41.8°C, while the triangular cross-section instruments presented an As of 36.9°C and an Af of 41.6°C. These findings indicate that both instruments maintained comparable phase transformation characteristics under the Blueish thermal treatment (Figure 3).

Cross-sectional area and metal mass volume

The results of the cross-sectional area (μm^2) and metal mass volume (mm^3) analyses are presented in Table 2. The S-shaped cross-section instruments exhibited a significantly lower metal mass volume at both 3 mm and 5 mm from the instrument's tip compared to the triangular cross-section instruments ($p < 0.05$). Similarly, the cross-sectional area of the S-shaped instruments was significantly smaller than triangular cross-sectional instruments ($p < 0.05$).

Mechanical tests

The results of cyclic fatigue, torsional resistance, and bending resistance tests are summarized in Table 3. The S-shaped cross-section instruments demonstrated significantly higher time to failure, NCF, and angular deflection compared to the triangular cross-section instruments ($p < 0.05$). Conversely, the triangular cross-section instruments exhibited higher torque and bending resistance (less flexibility) than the S-shaped cross-section instruments ($p < 0.05$).

Scanning electron microscopy evaluation

SEM analysis of the fractured surfaces revealed characteristic features of cyclic fatigue and torsional failure in

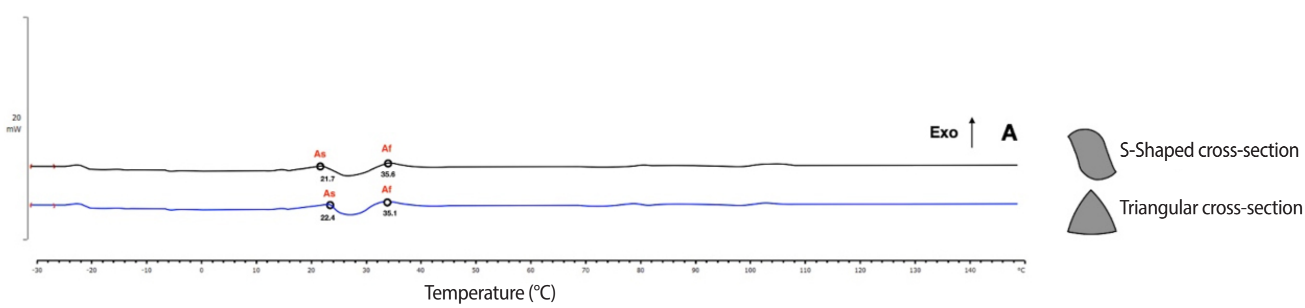

Figure 3. The differential scanning calorimetry (DSC) charts display the heating curves of the S-shaped and triangular cross-section instruments. The charts highlight the austenite start (As) temperature (on the left) and the austenite finish (Af) temperature (on the right) for each instrument. Overall, the DSC analysis revealed no significant difference in the phase transformation between the tested instruments.

Table 2. Metal mass volume and cross-section area measured at 3 mm and 5 mm from the tip of the tested instruments

Instrument	Metal mass volume (mm^3)		Cross-section area (μm^2)	
	3 mm	5 mm	3 mm	5 mm
S-Shaped	0.13 ± 0.01^A	0.36 ± 0.02^A	80.1 ± 0.3^A	122.4 ± 0.1^A
Triangular	0.18 ± 0.01^B	0.41 ± 0.02^B	91.7 ± 0.3^B	142.1 ± 0.1^B

Values are presented as mean ± standard deviation.
Different superscript letters in the same column indicate statistical differences between groups ($p < 0.05$).

Table 3. Cyclic fatigue[a)], torsional[b)], and bending[c)] resistance of the tested instruments

Instrument	Cyclic		Torsional		Bending 60º
	Time (sec)	NCF	Torque (N.cm)	Angular deflection (º)	Force (g/f)
S-Shaped	475 ± 26[A]	3165 ± 50[A]	0.89 ± 0.07[A]	467 ± 18[A]	112 ± 20[A]
Triangular	154 ± 31[B]	1030 ± 40[B]	1.27 ± 0.10[B]	347 ± 15[B]	156 ± 24[B]

Values are presented as mean ± standard deviation.
Different superscript letters in the same column indicate statistical differences between groups ($p < 0.05$).
[a)]Time to fracture and number of cycles to failure (NCF); [b)]maximum torque and angular deflection; [c)]force at 60° deflection.

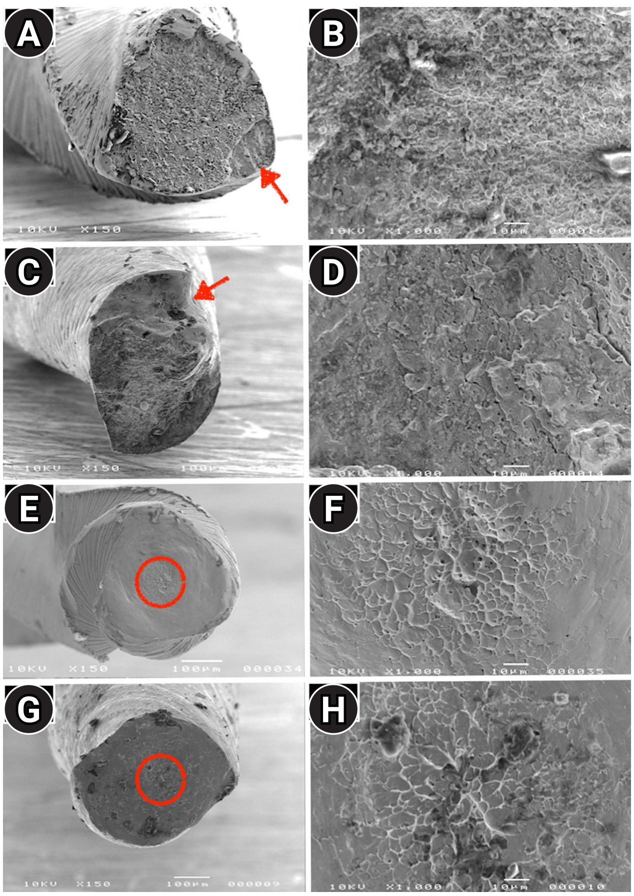

Figure 4. Scanning electron microscopy images of the fractured surfaces of the instrument fragments after cyclic (A–D) and torsional fatigue (E–H) testing, at 150× and 1,000× magnification. The cyclic fatigue images of the triangular (A, B) and S-shaped cross-section (C, D) show numerous dimples, characteristic of ductile fracture. The red arrows indicate the point of crack initiation. The torsional fatigue images of the triangular (E, F) and S-shaped cross-section (G, H) reveal concentric abrasion marks and skewed dimples near the center of rotation, which are typical features of torsional failure. The red circles indicate the point of concentric abrasion marks and skewed dimples.

both instrument groups. SEM images of the fractured surfaces of the instrument fragments after cyclic (Figure 4A–D) and torsional fatigue (Figure 4E–H) testing. The cyclic fatigue images of the triangular (Figure 4A, B) and S-shaped cross-section (Figure 4C, D) show a crack initiation area followed by numerous dimples, characteristic of ductile fracture. The torsional fatigue images of the triangular (Figure 4E, F) and S-shaped cross-section (Figure 4G, H) reveal concentric abrasion marks and fibrous dimples near the center of rotation, which are typical features of torsional failure.

DISCUSSION

The present study evaluated the influence of cross-section geometry on the mechanical performance of NiTi rotary instruments while eliminating confounding variables by maintaining identical tip size, taper, and thermal treatment. To assess how cross-section design affects mechanical behavior, three critical parameters were analyzed: cyclic fatigue resistance, torsional strength, and bending resistance. Previous studies have established that instrument design—including cross-section geometry, taper, and core diameter—directly impacts mechanical properties and fatigue resistance [3,7,8,13,14]. However, most of these studies compared instruments from different manufacturers or included additional design variations, making it difficult to isolate the specific effect of cross-section geometry [8,12–15]. To overcome this limitation, the present study was meticulously designed to ensure that all tested instruments underwent the same Blueish thermal treatment and shared identical tip size and taper. By standardizing these key parameters, this study provides a unique opportunity to assess the isolated effect of cross-section geometry on mechanical performance,

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free from extraneous variables. This methodological rigor minimizes bias, enhances the validity of the findings, and offers a precise evaluation of how cross-section geometry influences NiTi instrument behavior in endodontic applications.

In this study, DSC analysis was performed to confirm that both instruments underwent the same thermal treatment. Although both were produced by the same manufacturer and exhibited the characteristic Blueish coloration, DSC testing was essential because the machining process itself can alter the crystallographic structure of NiTi alloys. The results demonstrated that the As and Af temperatures were similar for both cross-section designs (Figure 2), confirming that no significant structural modifications occurred due to processing. At room temperature (20°C), both instruments remained in the martensitic phase, transitioning to an austenitic structure at body temperature (36°C). These findings were critical in ensuring that any differences in mechanical performance could be attributed exclusively to cross-section geometry, as no significant variations in thermal behavior or phase transformation were detected.

Prior to the mechanical tests, the instruments were scanned using micro-CT to perform both 2D (cross-sectional area, μm^2) and 3D (metal mass volume, mm^3) analyses at 3 mm and 5 mm from the instrument tip. This analysis allowed for a direct correlation between cross-section geometry and mechanical performance during testing. The results demonstrated that S-shaped cross-section instruments exhibited significantly lower metal mass volume and cross-section area compared to triangular cross-section instruments at both analyzed levels ($p < 0.05$) (Table 2). These findings confirm that cross-section geometry directly influences metal mass distribution, a key factor in determining flexibility, fatigue resistance, and overall mechanical behavior. Such an analysis is crucial for understanding how geometric modifications impact instrument performance, emphasizing the role of design parameters in shaping mechanical properties and their potential clinical implications [3,16].

During root canal preparation, NiTi instruments are subjected to both cyclic and torsional stresses, which are recognized as the primary causes of instrument failure [4,20]. Cyclic fatigue occurs due to repeated flexion of the instrument within curved canals, while torsional failure results from binding within narrow canal spaces, leading to excessive torque generation [20]. Laboratory tests assessing cyclic fatigue and torsional resistance serve as key indicators of an instrument's ability to withstand these failure modes under clinical conditions. Additionally, bending resistance tests are used to evaluate instrument flexibility, a crucial property that enhances centering ability in curved canals [3,16] and plays a significant role in determining fatigue resistance. However, while these laboratory tests provide valuable insights into mechanical behavior, their direct translation to clinical performance should be interpreted with caution, as *in vivo* conditions introduce additional variables that may influence instrument performance.

The mechanical test results demonstrated that S-shaped cross-section instruments exhibited superior performance in several parameters, including time to fracture, NCF, and angular deflection ($p < 0.05$) (Table 3). In contrast, the triangular cross-section instruments displayed significantly higher torque to fracture ($p < 0.05$) (Table 3). Given the statistically significant differences observed between the tested instruments, the null hypothesis was rejected. These findings confirm that cross-section geometry plays a critical role in determining the mechanical properties of NiTi instruments, as previously reported [7,8,12–15]. The lower metal mass volume and cross-section are of the S-shaped cross-section contributed to greater flexibility, which in turn explains its superior cyclic fatigue resistance, lower bending stiffness, and greater angular deflection in torsional tests. The combination of enhanced cyclic fatigue resistance and reduced bending stiffness may help reduce the risk of instrument fracture while improving root canal preservation, particularly in curved canals [3,7,8]. Additionally, the higher angular deflection observed in S-shaped instruments could provide clinicians with an early indication of plastic deformation, signaling an imminent risk of fracture [21]. The results of this study align with those reported by Kim *et al.* [12], which demonstrated that instruments with an S-shaped cross-section exhibit greater flexibility compared to those with a triangular cross-section. This finding confirms that S-shaped cross-sections tend to offer greater flexibility than triangular designs, as reported by previous authors [13–15]. Conversely, the higher torsional strength of the triangular cross-section is a relevant factor in the preparation of constricted canals, where instruments are subjected to greater torsional loads [21]. The highest torque to fracture of triangular cross-section instruments demonstrated in this study aligns with previous studies that reported higher torque to fracture than S-shaped cross-section instruments [12–15]. Therefore, the greatest torsional resistance of triangular cross-sections may offer resistance under high torsional stress, making them potentially more suitable for challenging canal anatomies requiring greater torque application, decreasing the risks of torsional failure. However, S-shaped instruments tend to exhibit greater cutting efficiency and an improved ability to reach the working length, which could enhance their performance even in constricted canals. Their sharper cutting edges and reduced metal mass may facilitate apical progression with less screwing-in effect, potentially minimizing the risk of excessive torsional stress. These factors suggest that, despite their lower torsional strength, S-shaped instruments could still perform effectively in narrow canals. Future studies with similar methodological designs should evaluate additional conditions to further clarify these findings and their impact on clinical outcomes.

This study has certain limitations that should be acknowledged. As a laboratory-based investigation, the experimental conditions do not fully replicate the complex *in vivo* environment, where factors such as dentin hardness, anatomical variations, and irrigation dynamics may influence instrument performance. Additionally, while this study successfully isolated cross-section geometry as the only variable, further research should explore its interaction with other parameters, such as kinematics and surface treatments, to provide a more comprehensive understanding of instrument behavior. Moreover, this study focused on specific mechanical properties, and additional tests could further clarify the clinical implications of cross-section geometry. Despite these limitations, the study's controlled methodology represents a key strength, allowing for an accurate assessment of how cross-section design influences mechanical properties. These findings have important clinical implications, such as instrument flexibility, fatigue resistance, and torsional strength are critical factors in preventing procedural errors and optimizing root canal preparation. Additionally, the use of complementary methodologies provided a more comprehensive dataset, enabling a deeper understanding of the relationship between instrument geometry and mechanical performance. By integrating different analytical techniques, this study moves beyond speculative assumptions, offering a more objective, data-driven interpretation of the findings. This approach strengthens the reliability of the results, reinforcing that cross-section geometry plays a decisive role in determining instrument behavior. Future studies should incorporate micro-CT analysis to evaluate the shaping ability of these instruments in anatomically complex canals, further validating their clinical applicability and guiding endodontists in selecting instruments that balance safety, efficiency, and durability.

CONCLUSIONS

Cross-section geometry significantly influences the mechanical properties of NiTi rotary instruments. The S-shaped cross-section exhibited lower metal mass volume, which contributed to greater flexibility and higher cyclic fatigue resistance. In contrast, the triangular cross-section demonstrated superior torque to fracture.

CONFLICT OF INTEREST

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AUTHOR CONTRIBUTIONS

Conceptualization: Vieira ART, Silva EJNL, Alcalde MP, Vivan RR, Duarte MAH. Data curation, Validation: all authors. Formal analysis: Alcalde MP, Duarte MAH, Silva EJNL. Funding acquisition: Alcalde MP. Investigation: Vieira ART, Silva EJNL, Amorim JVO, Lima TO, Oliveira Neto RS, Alcalde MP. Methodology: Silva EJNL, Silva GF, Duarte MAH, Vivan RR, Alcalde MP. Project administration: Vieira ART, Silva EJNL, Alcalde MP. Resources, Supervision, Software: Silva EJNL, Alcalde MP. Writing - original draft: Vieira ART, Silva EJNL, Alcalde MP. Writing - review & editing: Alcalde MP, Silva EJNL. All authors read and approved the final manuscript.

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DATA SHARING STATEMENT

The datasets are not publicly available but are available from the corresponding author upon reasonable request.

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Does the use of different root canal sealers and adhesive resin cements impact the bond strength of glass fiber posts?

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ABSTRACT

Objectives: This study aimed to assess the influence of two endodontic sealers on the bond strength of glass fiber posts using conventional and self-adhesive resin cement through a push-out test.
Methods: Forty central human incisors were randomly divided into four groups (n = 10) based on sealer (epoxy resin-based or calcium silicate-based) and cement (conventional and self-adhesive resin) types: AH Plus (Dentsply DeTrey)/RelyX ARC (3M ESPE), AH Plus/RelyX U200 (3M ESPE), Bio-C Sealer (Angelus)/RelyX ARC, and Bio-C Sealer/RelyX U200. After canal filling and post cementation, roots were sectioned to obtain one specimen per root third. A push-out test and failure pattern assessment were conducted, with bond strength analyzed using the one-way analysis of variance and Tukey test.
Results: AH Plus/RelyX ARC showed the highest bond strength values, with a significant difference in the middle third. The most common failure was mixed (55%), while adhesive failures made up 45%, with 23.5% at the cement/post interface and 21.5% at the cement/dentin interface.
Conclusions: AH Plus/RelyX ARC provided the highest bond strength values for glass fiber posts to dentin.

Keywords: Endodontics; Mechanical tests; Root canal filling materials; Resin cements

INTRODUCTION

Restoring teeth that have undergone endodontic treatment presents a distinct challenge, particularly when a significant portion of the coronal structure is compromised or entirely lost. In such scenarios, the prepared root canal space can serve as a foundation for post placement, which aids in retaining restorations like crowns or composite cores, ultimately enhancing the tooth's structural stability and function [1]. Among the

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various post options available, glass fiber posts have gained widespread use due to their favorable mechanical and aesthetic characteristics. Their elastic modulus closely resembles that of dentin, facilitating more uniform stress distribution within the tooth structure and consequently minimizing the likelihood of root fractures [2,3].

To minimize adhesive failures—commonly observed in clinical practice as the loss of retention of glass fiber posts—adhesive resin cements are widely recommended. These cements exhibit mechanical properties that harmonize with the composite system formed by the post, cement, and dentin, contributing to a more even stress distribution [4,5]. However, the cementation procedure involves multiple clinical steps, and its complexity may affect the integrity and longevity of the adhesive interface, thereby increasing the likelihood of long-term failure [6,7].

The use of conventional adhesive resin cement involves pretreating the root dentin with phosphoric acid and an adhesive system before applying the cement. In contrast, self-adhesive resin cements simplify this process by eliminating the need for pretreatment. Clinically, they offer advantages such as easier handling, enhanced flow, and reliable bonding to glass fiber posts through a combination of micromechanical interlocking and chemical adhesion [8,9]. Their formulation includes multifunctional hydrophilic monomers with phosphoric acid groups, which interact with hydroxyapatite and penetrate the smear layer [10,11]. This chemical interaction strengthens the bond to dentin [12], reducing the technique's sensitivity and reliance on operator skill.

Another key factor affecting the bond strength of glass fiber posts cemented with adhesive resin cement is the type and composition of the root canal sealer used to fill the root canal [13–16]. AH Plus (Dentsply DeTrey, Konstanz, Germany), an epoxy resin-based sealer, is widely considered the gold standard due to its superior physicochemical properties [17,18]. Meanwhile, calcium silicate-based sealers have gained popularity in endodontics for their excellent flow, ease of application, and bioactivity—specifically, their ability to form hydroxyapatite during setting [19,20]. Despite this, research on how these sealers influence the adhesion of glass fiber posts to dentin remains limited. The push-out test is a widely used mechanical test designed to evaluate the bond strength between a fiber post and the surrounding root canal dentin. In this test, a controlled force is applied to the post until debonding occurs, simulating the stresses experienced in clinical conditions. By providing a quantitative measure of interfacial adhesion, the push-out test is considered a reliable and reproducible method for assessing the effectiveness of different sealers and cement combinations in post retention.

In this context, the aim of the study was to evaluate the influence of two root canal sealers (AH Plus and Bio-C Sealer [Angelus, Londrina, Brazil]) on the bond strength of glass fiber posts to dentin. The evaluation utilized both conventional and self-adhesive resin cements (RelyX ARC [3M ESPE, Seefeld, Germany] and RelyX U200 [3M ESPE, Seefeld, Germany]), with measurements obtained through a push-out test. The null hypothesis tested was that neither the type of root canal sealer nor the type of resin cement (conventional vs. self-adhesive) would affect the bond strength of glass fiber posts to dentin.

METHODS

Sample size calculation

The determination of sample size was based on a previously published study that followed a comparable methodology [14]. The calculation was performed using an a priori analysis of variance (ANOVA) (fixed effects, omnibus, one-way) from the F-test family in G*Power 3.1.7 software for Windows (Heinrich Heine University Düsseldorf, Düsseldorf, Germany). An effect size of 0.91 was established, with an alpha error of 0.05 and a statistical power of 0.80, leading to a minimum requirement of nine specimens per group. To mitigate the risk of specimen loss, each group included 10 samples.

Specimen selection and grouping

After obtaining approval from the Grande Rio University (protocol no. 5.505.045), 60 extracted human maxillary central incisors, which were removed for reasons unrelated to this study, were initially selected. Patients' median age was 46 years (range, 24–78 years). Radiographs were taken in both mesiodistal and buccolingual directions to confirm the presence of straight root

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canals. Teeth presenting resorption, calcifications, root fractures, or prior endodontic treatment were excluded. As a result, 40 specimens met the inclusion criteria and were stored in a 0.1% thymol solution at 5°C until further use.

The crowns of the selected teeth were sectioned 1 mm above the cemento-enamel junction using a low-speed diamond disk, standardizing root lengths to 16 ± 1 mm, as verified with a digital caliper. The specimens were then randomly allocated into four experimental groups ($n = 10$) according to the combination of root canal sealers (epoxy resin-based or calcium silicate-based) and adhesive cements (conventional and self-adhesive resin) applied: AH Plus/RelyX ARC, AH Plus/RelyX U200, Bio-C Sealer/RelyX ARC, and Bio-C Sealer/RelyX U200 (Table 1).

Root canal preparation and filling

Following access cavity preparation, apical patency was verified by advancing a size 10 K-file (Dentsply Sirona Endodontics, Konstanz, Switzerland) until its tip extended slightly beyond the apical foramen. The working length (WL) was determined as 1.0 mm short of this point. A glide path was then established using a size 15 K-file (Dentsply Sirona Endodontics) up to the WL. To simulate a closed-end system, the apical third of each root was sealed with hot glue before embedding the specimens in polyvinyl siloxane (Speedex; Coltène, Cuyahoga Falls, OH, USA).

Root canal preparation was carried out using Reciproc Blue R50 instruments (VDW, Munich, Germany) with the VDW Silver motor set to the 'RECIPROC ALL' preset program. The instrument was gently advanced apically in a controlled in-and-out pecking motion with a 3-mm amplitude and minimal apical pressure until reaching the WL. After three pecking motions, the instrument was withdrawn and cleaned. Following each removal, 3 mL of 2.5% sodium hypochlorite (NaOCl) was delivered using a NaviTip 30-gauge needle (Ultradent Products Inc., South Jordan, UT, USA), positioned 2 mm short of the WL. Each canal received a total of 12 mL of 2.5% NaOCl for irrigation, followed by a final rinse with 3 mL of 17% EDTA and 5 mL of distilled water. All procedures were performed by a single experienced endodontist.

Table 1. List of materials with brands, batch number, and chemical composition

Material	Manufacturer/batch number	Composition
AH Plus Jet	Dentsply DeTrey, Konstanz, Germany	Paste A: bisphenol-A epoxy resin, bisphenol-F epoxy resin, calcium tungstate, zirconium oxide, silica, and iron oxide pigments
	Batch number: 22010001136	Paste B: dibenzyldiamine, aminoadamantane, tricyclodecane-diamine, calcium tungstate, zirconium oxide, silica, and silicone oil
Bio-C Sealer	Angelus, Londrina, Brazil Batch number: 59158	Calcium silicate, calcium aluminate, calcium oxide, zirconium oxide, iron oxide, silicon dioxide, and dispersing agent
Adper Scotchbond Multi-Purpose	3M ESPE, St. Paul, MN, USA	Primer: aqueous solution of HEMA and polyalcenoic acid copolymers
	Batch number: NE23064, NC50913, NC50196	Activator: ethyl alcohol, sodium benzenesulfinate
		Catalyst: bis-methacrylate of (1-methylethylidene) bis[4,1-phenyleneoxy and benzoyl peroxide
RelyX Silane Agent	3M ESPE, St. Paul, MN, USA Batch number: NA97783	Ethyl alcohol, water, 3-(trimethoxysilyl)propyl methacrylate
RelyX ARC	3M ESPE, Seefeld, Germany	Paste A: silane-treated ceramic, TEGDMA, Bis-GMA, silane-treated silica, functionalized dimethacrylate polymer, triphenylantimony
	Batch number: 2212900348	Paste B: silane-treated ceramic, TEGDMA, Bis-GMA, silane-treated silica, functionalized dimethacrylate polymer, 2-benzotriazolyl-4-methylphenol, benzoyl peroxide
RelyX U200	3M ESPE, Seefeld, Germany Batch number: 2201100350	Multifunctional phosphoric acid methacrylates, dimethacrylates, acetate, initiator/stabilizer, powdered glass, silica, substituted pyrimidine, calcium hydroxide, peroxide compound, pigments

HEMA, 2-hydroxyethyl methacrylate; TEGDMA, triethylene glycol dimethacrylate; Bis-GMA, bisphenol A-glycidyl methacrylate.

The root canals were dried using Reciproc Blue R50 absorbent paper points (VDW) and subsequently filled with Reciproc Blue R50 gutta-percha cones (VDW) using the single-cone technique. AH Plus Jet and Bio-C Sealer were employed as sealers according to the assigned groups. In the AH Plus Jet groups, the sealer was mixed using the automix tip and introduced into the canal. For the Bio-C Sealer groups, the sealer was dispensed with the provided needle. A Reciproc Blue R50 gutta-percha cone was then inserted up to the WL. Excess gutta-percha was eliminated with a heat carrier and compacted vertically using a condenser. To assess the quality of the root canal filling, digital radiographs were taken from both buccolingual and mesiodistal perspectives. The access cavities were sealed with light-cure glass ionomer, and all specimens were stored at 37°C with 100% humidity for 1 week.

Glass fiber post cementation procedures

The root canals were re-accessed using diamond burs under continuous water cooling, and part of the root canal filling was removed with size 2 Largo Peeso drills (Dentsply Maillefer Endodontics), leaving 5 mm of gutta-percha in the apical third. Digital radiographs were taken to verify the complete removal of the filling material. The post space was then prepared to a depth of 10 mm using the corresponding bur from the Exacto glass fiber post system (Angelus) to accommodate a size 2 post. After preparation, the canal space was rinsed with 5 mL of distilled water and dried using Reciproc Blue R50 absorbent paper points.

Glass fiber posts were cleaned by immersion in 70% ethyl alcohol for 1 minute and subsequently silanized with RelyX Silane Agent (3M ESPE, St. Paul, MN, USA) using a disposable microbrush, allowing a reaction time of 1 minute. This step was performed immediately before cementation for all posts, regardless of the group.

In the AH Plus/RelyX ARC and Bio-C Sealer/RelyX ARC groups, the root canal walls were treated with 37% phosphoric acid for 15 seconds, followed by rinsing with distilled water for 30 seconds and drying with absorbent paper points. The Adper Scotchbond Multi-Purpose adhesive system (3M ESPE, St. Paul, MN, USA) was applied, with the primer actively brushed for 10 seconds, followed by an air jet for another 10 seconds. The adhesive was then applied to the canal walls for an additional 10 seconds using a microbrush and light cured with the Valo Grand Cordless light-curing unit (Ultradent Products Inc.). RelyX ARC cement was dispensed into the root canal using automix tips, the fiber post was positioned, and light curing was performed for 40 seconds.

For the AH Plus/RelyX U200 and Bio-C Sealer/RelyX U200 groups, RelyX U200 self-adhesive resin cement was mixed and applied directly into the canals using automix tips, without prior dentin treatment. The fiber post was then positioned and light cured for 40 seconds.

All procedures were performed by a single endodontist, and the specimens were stored at 37°C with 100% humidity for 1 week.

Push-out test and failure pattern analysis

The roots were embedded in chemically cured acrylic resin blocks and transversely sectioned using a diamond disc under continuous water cooling with a precision cutting machine (Isomet 1000; Buehler, Lake Forest, IL, USA). Each specimen was sectioned into three slices, measuring 2 ± 0.3 mm in thickness, corresponding to the cervical, middle, and apical thirds of the post space. Each group produced 30 slices, with 10 from each third (n = 10), totaling 120 slices. No specimens were lost during sectioning. To avoid any compromise to the cement interface, push-out tests were performed immediately after sectioning (Figure 1).

Each slice was positioned on a metallic device with a central opening (Ø = 3 mm), ensuring that the canal diameter remained unrestricted. A metallic cylinder with an active tip (Ø tip = 0.8 mm) applied force in an apical-to-coronal direction, preventing pressure on the cement or dentin during testing.

The push-out test was conducted using a universal testing machine (Emic DL-2000; Emic, São José dos Pinhais, Brazil) operating at a speed of 1 mm/min. Bond strength values (σ) in MPa were determined using the equation: $\sigma = F/A$, where F is the fracture load (N), and A represents the area of the fiber post (mm^2). The post area was calculated with the formula: $A = 2 \times \pi \times g\ (R1 + R2)$, where $\pi = 3.14$, g = slant height, $R1$ = smaller base radius, and $R2$ = larger base radius. The slant height was determined using the equation: $g^2 = (h^2 + [R2 - R1]^2)$, where h is the section height. $R1$ and $R2$ corresponded

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Total samples:
40 Teeth
120 Slices

	Group 1 AH Plus / RelyX ARC	Group 2 AH Plus / RelyX U200	Group 3 Bio-C / RelyX ARC	Group 4 Bio-C / RelyX U200
Cervical	10 slices	10 slices	10 slices	10 slices
Middle	10 slices	10 slices	10 slices	10 slices
Apical	10 slices	10 slices	10 slices	10 slices

Figure 1. Flowchart of slices per experimental group.

to the internal diameters of the smaller and larger bases, measured to reflect the space between the root canal walls. A digital caliper was used for all diameter and height measurements. One blinded operator conducted the push-out tests, while another was responsible for the measurements.

Each slice was examined under a stereomicroscope (StereoDiscovery V20; Carl Zeiss, Göttingen, Germany) at 10× magnification by two operators. In cases where discrepancies arose, a third operator provided the final assessment. Failure patterns were categorized as follows: adhesive at the cement/dentin interface, adhesive at the cement/post interface, cohesive in the dentin, cohesive in the cement, cohesive in the post, and mixed. Mixed failures included cohesive failure in the cement combined with adhesive failure at the post-cement interface, cohesive failure in the cement with adhesive failure at the cement-dentin interface, or a combination of adhesive failures at both interfaces with cohesive failure in the cement (Figure 2).

Statistical analysis

Data were statistically analyzed using BioEstat ver. 5.0 software (AnalystSoft Inc., Walnut, CA, USA). The Kruskal-Wallis normality test confirmed a normal distribution of the data. Overall, the data followed a Gaussian curve (Shapiro-Wilk test, $p < 0.05$). Based on this observation, one-way ANOVA and Tukey tests were employed to estimate the impact of independent variables among the groups (AH Plus/RelyX ARC, AH Plus/RelyX U200, Bio-C Sealer/RelyX ARC, and Bio-C Sealer/RelyX U200) on the push-out resistance for the different endodontic sealers and adhesive resin cements in all thirds of the root canal. The significance level was set at 0.05.

RESULTS

Table 2 shows the mean bond strength values for each experimental group, based on the root canal sealer and resin cement used for fiber post cementation. Intergroup analysis indicated that the AH Plus/RelyX ARC combination achieved the highest bond strength values in the middle third ($p < 0.05$). In the apical third, AH Plus/RelyX ARC showed a statistically significant difference compared to the AH Plus/RelyX U200 and Bio-C Sealer/U200 groups ($p < 0.05$). Intragroup analysis showed no significant differences between the thirds of the root within any of the four groups ($p > 0.05$).

Table 3 shows the distribution of failure patterns, with mixed failure being the most common type, occurring in about 55% of specimens. This included adhesive failures at both the cement/post and cement/dentin interfaces, as well as cohesive failures within the cement. Adhesive failures accounted for nearly 45% of the cases, with 23.5% occurring at the cement/post interface and 21.5% at the cement/dentin interface.

DISCUSSION

This study assessed the impact of an epoxy resin-based sealer (AH Plus Jet) and a calcium silicate-based sealer (Bio-C Sealer) on the bond strength of glass fiber posts

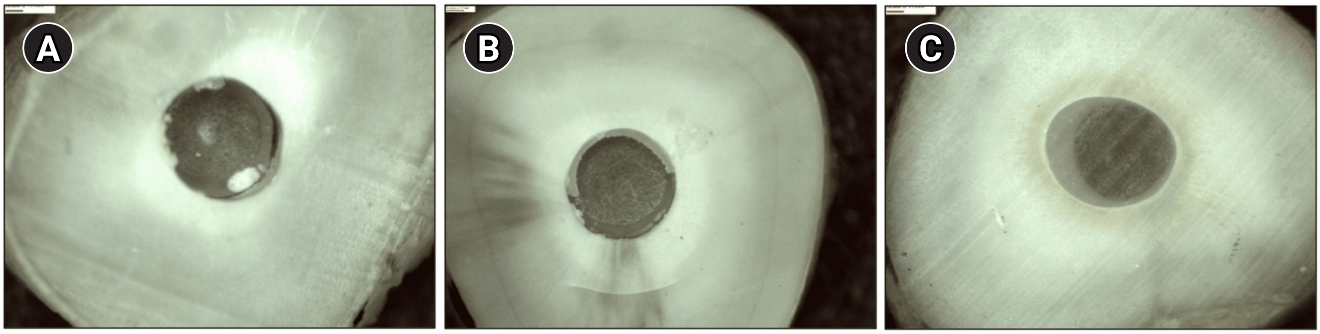

Figure 2. Failures observed in the present study. (A) Adhesive failure at the cement-dentin interface. (B) Mixed failure: adhesive at the post-cement interface, adhesive at the cement-dentin interface, and cohesive in cement. (C) Adhesive failure at the cement-post interface.

Table 2. Values of bond strength for the experimental groups after the push-out test

Group	Bond strength (MPa)		
	Cervical	Middle	Apical
AH Plus and RelyX ARC	3.44 ± 2.9^{Aa}	5.55 ± 1.9^{Aa}	4.34 ± 3.0^{Aa}
AH Plus and RelyX U200	1.50 ± 1.1^{Aa}	1.39 ± 0.9^{Ba}	1.03 ± 0.8^{Ba}
Bio-C Sealer and RelyX ARC	2.73 ± 1.5^{Aa}	3.14 ± 1.4^{Ba}	2.33 ± 2.0^{ABa}
Bio-C Sealer and RelyX U200	2.28 ± 1.5^{Aa}	1.88 ± 1.4^{Ba}	1.06 ± 0.6^{Ba}

Values are presented as mean ± standard deviation.
AH Plus: Dentsply Maillefer, Konstanz, Switzerland; RelyX ARC: 3M ESPE, Seefeld, Germany; RelyX U200: 3M ESPE, Seefeld, Germany; Bio-C Sealer: Angelus, Londrina, Brazil.
Different uppercase letters in the columns indicate significant differences between groups within the same third ($p < 0.05$). Different lowercase letters in the rows indicate significant differences between thirds within each group ($p < 0.05$).

cemented with either conventional adhesive resin cement (RelyX ARC) or self-adhesive resin cement (RelyX U200) using a push-out test. Notably, the AH Plus/RelyX ARC combination yielded the highest bond strength in the middle third ($p < 0.05$). In the apical third, this combination exhibited significantly higher bond strength than both the AH Plus/RelyX U200 and Bio-C Sealer/RelyX U200 groups ($p < 0.05$). These findings led to the rejection of the null hypothesis, underscoring that both the type of sealer and the choice of resin cement significantly impact bond strength outcomes.

As previously noted, the type of root canal sealer can influence the bond between adhesive resin cement and glass fiber posts [13,14]. In this study, the Bio-C Sealer/RelyX ARC group exhibited a nearly 40% reduction in bond strength compared to AH Plus/RelyX ARC. This finding aligns with previous research, which indicated that calcium silicate-based root canal sealers negatively affect the bond strength of glass fiber posts to root dentin [14,21]. Despite efforts to thoroughly remove filling materials before post cementation, residual calcium silicate-based sealer may remain embedded in the dentinal tubules, influencing outcomes even after post space cleaning and preparation [21,22]. Additionally, tag-like structures, consisting of either sealers or hydroxyapatite crystals, may form, suggesting intratubular precipitation [23]. These calcium- and phosphate-rich precipitates, due to the high alkaline pH, can diminish the effectiveness of phosphoric acid etching and impede the formation of a hybrid layer with conventional adhesive resin cement [23]. On the other hand, the superior results observed with the combination of AH Plus root canal sealer and RelyX ARC, a conventional adhesive resin cement, may be attributed to the compatibility between the components of the epoxy resin-based sealer and the adhesive resin cement used for fiber post cementation [24]. This compatibility potentially facilitates stronger adhesion by promoting a more cohesive and durable bond interface between the resin cement and root dentin, further underscoring the importance of sealer choice in enhancing post retention and long-term stability.

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Table 3. Percentage distribution of failure modes across the analyzed groups

Failure mode	Group															
	AH Plus and RelyX ARC				AH Plus and RelyX U200				Bio-C Sealer and RelyX ARC				Bio-C Sealer and RelyX U200			
	Cervical	Middle	Apical	Total	Cervical	Middle	Apical	Total	Cervical	Middle	Apical	Total	Cervical	Middle	Apical	Total
Adhesive at cement-post interface	8 (80)	5 (50)	8 (80)	21 (70)	3 (30)	2 (20)	0 (0)	5 (17)	0 (0)	0 (0)	0 (0)	0 (0)	1 (10)	1 (10)	1 (10)	3 (10)
Adhesive at cement-dentin interface	0 (0)	0 (0)	0 (0)	0 (0)	1 (20)	2 (20)	1 (10)	4 (13)	6 (40)	5 (50)	8 (80)	19 (63)	3 (30)	0 (0)	0 (0)	3 (10)
Cohesive in dentin	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Cohesive in cement	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Cohesive in post	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Mixed: cohesive in cement and adhesive at post-cement interface	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Mixed: cohesive in cement and adhesive at cement-dentin interface	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Mixed: adhesive at post-cement interface, adhesive at cement-dentin interface, and cohesive in cement	2 (20)	5 (50)	2 (20)	9 (30)	6 (60)	6 (60)	9 (90)	21 (70)	4 (40)	5 (50)	2 (20)	11 (37)	6 (60)	9 (90)	9 (90)	24 (80)

Values are presented as number (%).
AH Plus: Dentsply Maillefer, Konstanz, Switzerland; RelyX ARC: 3M ESPE, Seefeld, Germany; RelyX U200: 3M ESPE, Seefeld, Germany; Bio-C Sealer: Angelus, Londrina, Brazil.ww

Self-adhesive cements provide a convenient alternative for cementing glass fiber posts by simplifying the application process and ensuring strong adhesion to dental structures. They reduce working time by eliminating steps such as acid etching, primer application, and adhesive placement on the dental substrate [12,25]. Despite these advantages, the groups cemented with the self-adhesive RelyX U200 exhibited the lowest bond strength values, regardless of the root canal sealer used. This reduced performance may stem from the acidic resin monomers in RelyX U200, which, though formulated for enamel and dentine etching, may not achieve the same depth of demineralization as phosphoric acid [26,27]. These results are consistent with previous studies showing that conventional adhesive cements typically achieve higher bond strength values than self-adhesive options [26,27].

The study results indicated a predominance of mixed failures (55%) in the push-out tests, whereas adhesive failures constituted 45% of failures, with 23.5% occurring at the cement/post interface and 21.5% at the cement/dentin interface. Notably, the Bio-C Sealer/RelyX U200 combination demonstrated a higher frequency of mixed failures, which may suggest a strong interaction between the calcium silicate-based sealer and the self-adhesive resin cement [13]. In contrast, in the Bio-C Sealer/RelyX ARC group, adhesive failures at the cement/dentin interface were predominant, potentially due to residual filling materials on the dentinal walls, which could reduce bonding efficiency [22]. For the AH Plus/RelyX ARC combination, most failures were adhesive at the cement/post interface, likely reflecting the influence of post surface treatment on cement adhesion. In this study, the glass fiber post was cleaned with alcohol and treated with silane, aiming to enhance bonding at this interface [2]. When AH Plus was used with RelyX U200, mixed failures were more prevalent, suggesting a satisfactory bond between the epoxy-based sealer and the self-adhesive resin cement, underscoring the compatibility of these materials in terms of bonding performance. Importantly, when analyzing failure distribution patterns, it becomes evident that the type of resin cement had a greater influence than the type of endodontic sealer. In both groups where RelyX U200 was used, regardless of whether Bio-C Sealer or AH Plus

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was applied, mixed failures were predominant. Conversely, in groups where RelyX ARC was used, failure modes varied according to the sealer: adhesive failures at the cement/post interface when combined with AH Plus and at the cement/dentin interface when combined with Bio-C Sealer. This suggests that the adhesive strategy of the resin cement played a more decisive role in determining the failure mode than the endodontic sealer itself. These findings reinforce the importance of selecting an appropriate resin cement to optimize post retention and interfacial adhesion.

While these laboratory tests were conducted in controlled settings, caution is warranted when applying these results directly to clinical practice. Nonetheless, the study offers significant insights by systematically evaluating how different sealer-cement combinations influence bond strength, providing a detailed understanding of material compatibility and its impact on restoration integrity. The inclusion of two commonly used resin cements and root canal sealers further adds clinical relevance, enabling a more comprehensive perspective on adhesive performance across diverse restorative scenarios.

Clinically, these findings underscore the need for practitioners to carefully select sealers and cements based on their compatibility, particularly in cases involving high stress or complex post and core restorations. Future studies should seek to confirm these *in vitro* results through *in vivo* trials that assess long-term performance, ideally exploring the specific interactions between calcium silicate-based sealers and adhesive cements under variable conditions, such as temperature changes, and masticatory forces. In addition, the effect of sealers on the dentin microstructure at the microscopic level should also be investigated. Expanding this research could help refine adhesive strategies and optimize the success of restorations involving fiber-reinforced posts, ensuring they meet both functional and aesthetic demands in clinical applications.

CONCLUSIONS

The combination of AH Plus root canal sealer with RelyX ARC cement provided the highest bond strength values to dentin for glass fiber posts. The authors declare no other conflicts of interest.

CONFLICT OF INTEREST

Emmanuel João Nogueira Leal da Silva is the Associate Editor of *Restorative Dentistry and Endodontics* and was not involved in the review process of this article.

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AUTHOR CONTRIBUTIONS

Conceptualization, Data curation: Porto ARNP, da Silva EJNL. Formal analysis, Investigation, Methodology: all authors. Funding acquisition, Project administration, Resources, Supervision: da Silva EJNL. Software: Porto ARNP, Belladonna FG, Vieira VTL. Writing - original draft: Porto ARNP, Moreira RF, Vieira VTL. Writing - review & editing: Belladonna FG, da Silva EJNL. All authors read and approved the final manuscript.

DATA SHARING STATEMENT

The datasets are not publicly available but are available from the corresponding author upon reasonable request.

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Structural and morphological characterization of silver nanoparticles intruded mineral trioxide aggregate admixture as a chair-side restorative medicament: an *in vitro* experimental study

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ABSTRACT

Objectives: The aim of this study was to create a rapid admixture of mineral trioxide aggregate (MTA) and silver nanoparticles (AgNPs) for chairside use in clinical settings to remediate the challenges associated with root canal treatment and pulp capping.
Methods: Synthesized AgNPs at ratios of 10 and 25% were added to commercially available MTA to create an admixture. The admixture was subjected to structural and morphological assessment using X-ray diffraction analysis (XRD), Fourier transform infrared (FT-IR) analysis, Raman spectroscopy, and scanning electron microscopy. Antioxidant activity was measured using the hydroxyl radical scavenging assay. A significance level of 0.05 was applied to determine statistical differences.
Results: The addition of AgNPs decreased the carbonate peak intensity in XRD and FT-IR. The rod-like morphology of MTA was changed to a flake-like morphology with the addition of AgNPs. Antibacterial efficacy enhanced proportionally with the augmentation of AgNPs concentration.
Conclusions: The creation of rapid admixture of MTA and AgNPs during chairside use in clinical settings can deliver beneficial characteristics of enhanced morphological features favoring mineralization and profound antibacterial effects to overcome the challenges associated with root canal treatment and pulp capping.

Keywords: Mineral trioxide aggregate; Nanoparticles; Pulp capping; Silver

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INTRODUCTION

The primary objective of endodontic therapy is to eradicate all microorganisms within the root canal and effectively seal any potential communication channels between the pulp and surrounding tissues [1,2]. Among currently available root-end filling materials, mineral trioxide aggregate (MTA) plays a pivotal role in restorative dentistry with improved biocompatibility and sealing ability [3]. MTA is a bioceramic with primary components consisting of tricalcium silicate, dicalcium silicate, and tricalcium aluminate. Key indications of MTA are root-end filling, pulp capping, pulpotomy, root perforation repair, apexification, and regenerative endodontics [4].

The antimicrobial property of MTA is limited, and MTA exhibits synergistic antimicrobial properties when mixed with other substances or medications frequently employed in endodontic treatment, such as chlorhexidine or antibiotics. These combinations have demonstrated improved antibacterial effectiveness [5]. Incorporation of silver (Ag) into MTA could also enhance the antibacterial characteristics, increasing its efficacy in treating bacterial infections in dental applications [6,7]. The antibacterial properties of silver have been widely acknowledged for their effectiveness against a wide range of pathogens found in endodontic infections. The inclusion of silver in MTA offers supplementary advantages in endodontic treatment that include reduced microleakage, extended longevity, and enhanced biocompatibility [8].

Literature has revealed that combining silver nanoparticles (AgNPs) with MTA is an attractive option as a novel retrograde filling, with increased effectiveness of AgNPs in inhibiting the growth of *Enterococcus faecalis* [9,10]. Similarly, MTA and calcium-enriched mixture incorporated with AgNPs had a significant effect on bacteria associated with dental infections [10]. Further, the morphology of the mineral composites also influenced the material's efficiency in endodontics. The elongated form of rod-like particles enhanced infiltration into the adjacent tissues or biomaterial matrices, thus strengthening the interactions between MTA particles and the surrounding environment, favoring apatite formation [9,11]. Despite promising results, there is no product that has been translated into clinical use.

The creation of a rapid admixture of MTA and AgNPs for chairside use in clinical settings could serve as a practical way to achieve the beneficial characteristics of enhanced mineralization and antioxidant effects. Such synergistic actions are crucial to remediate the challenges associated with root canal treatment and pulp capping. This study aimed to enhance the properties of three different commercially available MTAs, including MTA White, MTA Plus, and MTA Repair, by incorporating AgNPs. Additionally, structural, morphological, and antibacterial characteristics were evaluated.

METHODS

Synthesis of silver nanoparticles

AgNPs were synthesized utilizing a chemical reduction approach [12]. Constituents of reactive materials were produced in double-distilled water. For the standard procedure, a solution containing 50 mL of silver nitrate ($AgNO_3$) with a concentration of 1×10^{-3} M was heated until it reached its boiling point. A volume of 5 mL of 1% sodium borohydride ($NaBH_4$) was added gradually to this mixture. The solution was vigorously agitated during this procedure and heated until a discernible change in color (light brown) occurred. Eventually, it was extracted in powder form (50–80 nm) from the heating component and agitated until it reached the ambient temperature of 100°C for 12 hours [13].

Silver nanoparticles intruded mineral trioxide aggregate admixture

Physical mixing of varying ratios of AgNPs (10% and 25%) with different brands of MTA White (Angelus, Londrina, Brazil), MTA Plus (Prevest DenPro, Jammu, India), and MTA Insta Repair (Raman Research Products, Bangalore, India) was carried out. The numbers '10' and '25' indicate the content (wt%) of AgNPs. Samples were run in triplicate in similar experimental conditions with a total sample size of $n = 27$ (9 samples per group). An admixture of 3 g was dispensed on a paper pad and mixed with sterile water in the ratio of 0.26, using a plastic spatula for a duration of 1 to 3 minutes till a thick paste-like consistency was achieved. The mixture was separated into portions and allowed to set for 30 minutes.

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Characterization

MTA-AgNP admixture was analyzed for X-ray diffraction patterns to assess the crystalline phases with the wavelength Cu Kα (Bruker D8 Advance; Bruker, Karlsruhe, Germany). Functional group properties were analyzed through Raman spectroscopy (ALPHA300 RA; WITec, Ulm, Germany). Morphological and elemental analyses were done using scanning electron microscopy (SEM) (JSM-IT 800; JEOL, Tokyo, Japan). The samples were loaded onto the stub using adhesive tape and sputter-coated with platinum. Imaging of the sample was done at a scale of 1 μm.

Antioxidant activity

The hydroxyl radical scavenging assay was done by taking a known volume of the test sample [14]. The mixture was made as a 10 mM stock solution and incubated for 30 minutes at 37°C to allow hydroxyl radicals to react. Following the addition of 1 mL of 10% trichloroacetic acid and 1 mL of 1% thiobarbituric acid solution, the reaction was then stopped by heating the mixture in a boiling water bath for 30 minutes to generate a pink complex denoting the endpoint. Following cooling, a spectrophotometer was used to measure the absorbance at 532 nm. The hydroxyl radical scavenging activity was then calculated as a percentage using the following formula: % scavenging activity = [(control absorbance – sample absorbance) / control absorbance] × 100. The results were validated by including the appropriate controls and replicates [15].

Statistical analysis

Statistical analysis was performed to evaluate differences in antioxidant potential based on the percentage of reduction achieved across three groups at varying concentrations. A one-way analysis of variance (ANOVA) test was performed, as the data followed a normal distribution, had similar variances, and were independent measurements. ANOVA was used to calculate the *F*-statistic. A significance level of $p < 0.05$ was applied to determine statistically meaningful differences. The analysis was performed using IBM SPSS version 24 (IBM Corp, Armonk, NY, USA).

RESULTS

Structural analysis

MTA contains calcium silicate as a major component along with traces of zirconia, bismuth, and phosphate. In the case of X-ray diffraction dominant Ca_3SiO_5 crystalline phase was noted along with the diffracted peaks of $CaCO_3$.

Fourier transform infrared (FT-IR) spectra demonstrated in Figure 1 revealed silica (460 cm^{-1}) and phosphate (575 cm^{-1}) vibrations, indicating the presence of bioceramics. The Ca_3SiO_5 crystalline phase was evinced as the primary phase along with $CaCO_3$. When compared to MTA White samples, some noise peaks were observed, intense 29° peaks indicating dominant calcium carbonate were also noted. The $CaCO_3$ peak appears suppressed in the presence of AgNPs. Compared to MTA White samples, deep silica and phosphate vibrations were noted in other samples, along with sharp crystalline peaks exhibited in X-ray diffraction analysis (XRD) [11,16].

Morphological analysis

Imaging of the samples was done using SEM at 1 μm as illustrated in Figure 2. Tiny rod-shaped morphology was evident in the pure MTA White sample. After introducing silver into MTA White sample, AgNPs displayed flake-like morphology. Further, rods are joined together to form an interconnected bunch-rod appearance in MTA Plus samples. Infusion of silver on bunched rod appearances resulted in flakes and sheet-like morphology. Increasing the concentration of small spherical silver particles with the integration of bunched rods was perceptible. Non-homogeneous spiky rods, as well as elongated sheet-like morphology, were noted in pure MTA Insta Repair. Further addition of silver into these rods and sheets revealed integrated flake-like morphology.

Antioxidant activity

The hydroxyl radical scavenging assay, revealed in Figures 3 and 4, demonstrated the ability of the samples to neutralize harmful hydroxyl radicals. Results demonstrated that all samples with AgNPs exhibited antioxidant activity. The inter-group comparison of antioxidant

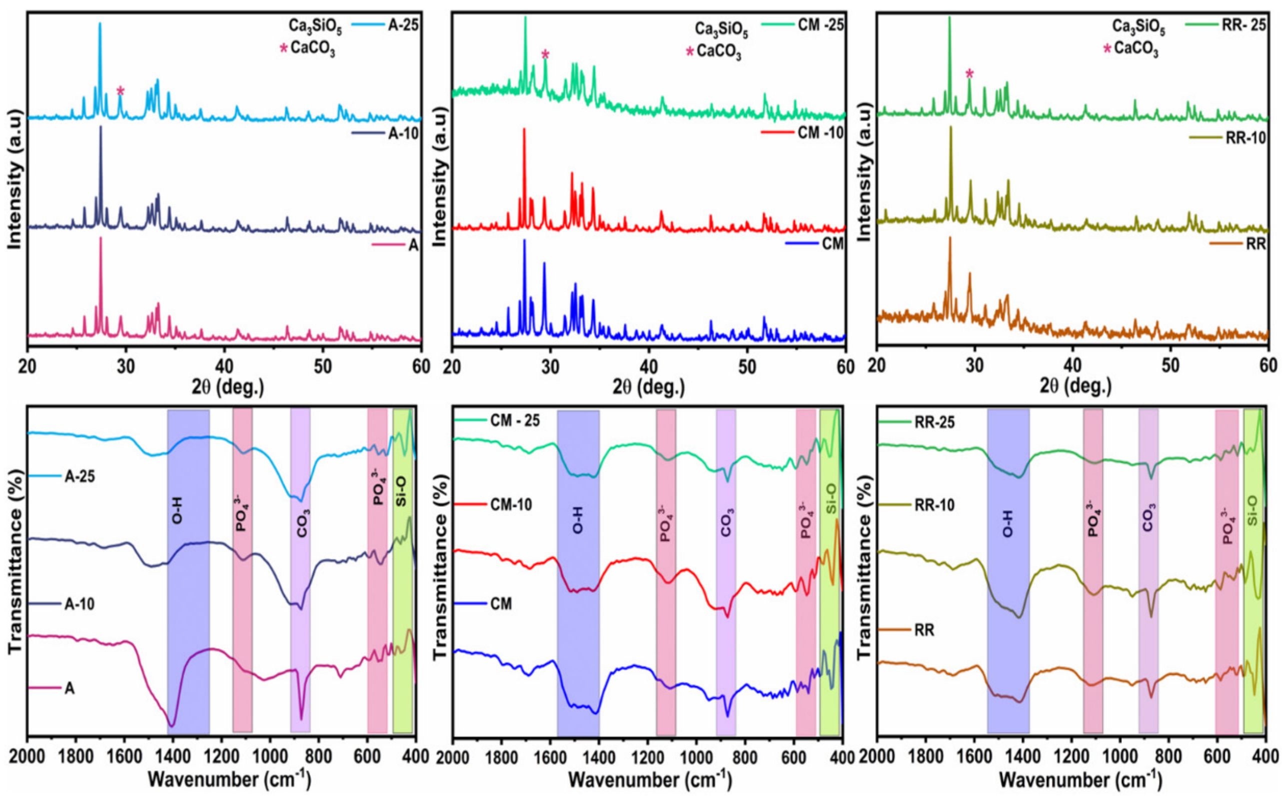

Figure 1. X-ray diffraction (XRD) and Fourier transform infrared (FT-IR) spectra of the tested materials. (A) XRD spectra of pure MTA White (denoted as 'A'), A-10, and A-25. (B) XRD spectra of MTA Plus (denoted as 'CM'), CM-10, and CM-25. (C) XRD spectra of pure MTA Insta Repair (denoted as 'RR'), RR-10, and RR-25. (D) FT-IR spectra of A, A-10, and A-25. (E) FT-IR spectra of CM, CM-10, and CM-25. (F) FT-IR spectra of RR, RR-10, and RR-25. *10 and 25 represent the contents (mg) of silver nanoparticles in pure base materials, including A, RR, and CM, respectively. MTA White: Angelus, Londrina, Brazil; MTA Plus: Prevest DenPro, Jammu, India; MTA Insta Repair: Raman Research Products, Bangalore, India.

activity of the three materials (MTA White, MTA Plus, and MTA Insta Repair) was analyzed using one-way ANOVA to assess the differences in reduction percentage with different concentrations of AgNPs (pure; 10 mg and 25 mg). Statistical significance was observed in all materials, with *F*-statistics of 221.71 ($p = 2.38 \times 10^{-6}$) for MTA White, 160.33 ($p = 6.20 \times 10^{-6}$) for MTA Plus, and 72.33 ($p = 6.32 \times 10^{-5}$) for MTA Insta Repair. Further, intragroup comparison was done using repeated measures ANOVA. Results revealed statistically significant differences within each dental cement group. In MTA White group, *F*-statistic was 221.71 with a *p*-value of 2.38×10^{-6} 2.38×10^{-6}. MTA Plus group exhibited significant variation with an *F*-statistic of 160.33 and a *p*-value of 6.20×10^{-6}. MTA Insta Repair group also demonstrated significant differences, with an *F*-statistic of 72.33 and a *p*-value of 6.32×10^{-5}. The results revealed that AgNPs exhibit a significant hydroxyl radical scavenging ability.

DISCUSSION

MTA has emerged as a versatile material for root-end filling and pulp-capping agents due to its bioactive and biocompatible properties. Additional properties like good sealing ability, setting properties, and antimicrobial potential have made it the most sought-after bioactive material in endodontics [17]. However, the antimicrobial property of MTA is potentially less; enhancing the antibacterial property of MTA is of profound importance, considering the increasing evidence of persistent periapical infections. The addition of AgNPs to the MTA matrix has been reported by multiple studies to improve antimicrobial properties. The lower concentrations of AgNPs have also been demonstrated to impart sufficient

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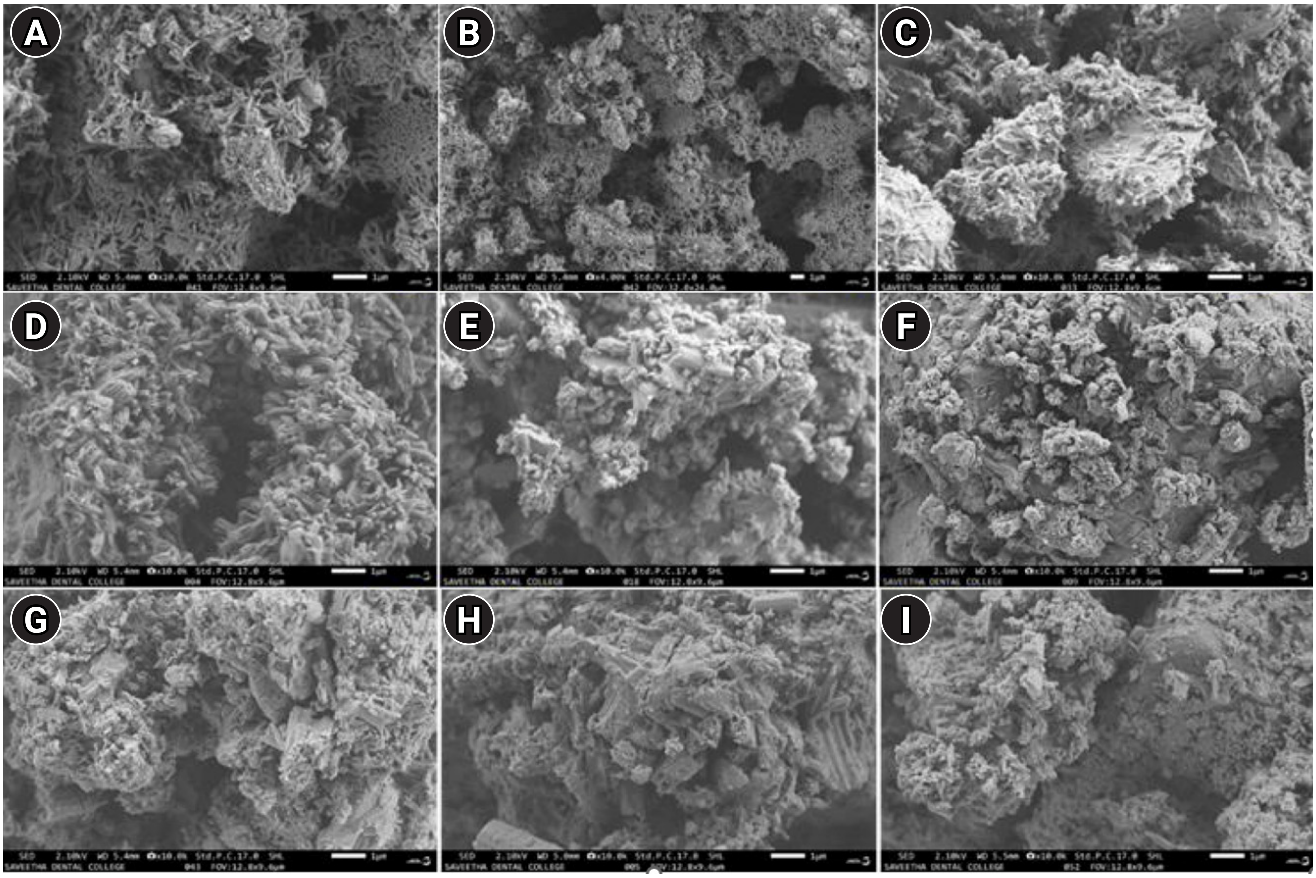

Figure 2. Scanning electron microscopy (SEM) images showing the morphological characteristics of the tested materials. (A) Pure MTA White (denoted as 'A'). (B) A + 10 mg silver nanoparticles (AgNPs). (C) A + 25 mg AgNPs. (D) Pure MTA Plus (denoted as 'CM'). (E) CM + 10 mg AgNPs. (F) CM + 25 mg AgNPs. (G) Pure MTA Insta Repair (denoted as 'RR'). (H) RR + 10 mg AgNPs. (I) RR + 25 mg AgNPs. MTA White: Angelus, Londrina, Brazil; MTA Plus: Prevest DenPro, Jammu, India; MTA Insta Repair: Raman Research Products, Bangalore, India.

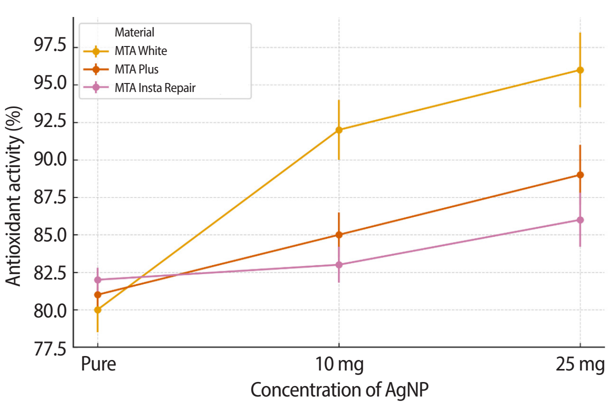

Figure 3. Intergroup comparison of the antioxidant activity of MTA White group, MTA Plus group, and MTA Insta Repair group. AgNP, silver nanoparticle. MTA White: Angelus, Londrina, Brazil; MTA Plus: Prevest DenPro, Jammu, India; MTA Insta Repair: Raman Research Products, Bangalore, India.

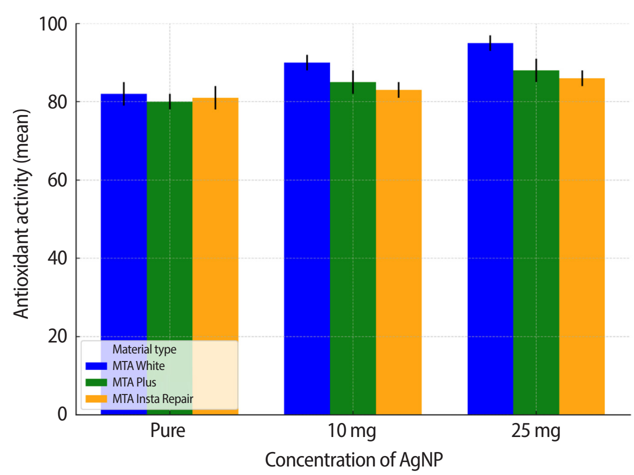

Figure 4. Intra-group comparison of the antioxidant activity. AgNP, silver nanoparticle. MTA White: Angelus, Londrina, Brazil; MTA Plus: Prevest DenPro, Jammu, India; MTA Insta Repair: Raman Research Products, Bangalore, India.

antimicrobial properties while maintaining the biocompatibility and mechanical integrity of MTA [9]. Although the results have shown promise, there are currently no products that are available for clinical use. Developing a quick and easy mixture of MTA and AgNPs for use directly in the dental office as an admixture could be a practical approach to benefit from the advantages. The current study focused on validating the structure and morphology of an MTA mixture infused with AgNPs.

AgNPs have been a versatile source to increase antimicrobial activity. Their addition tends to alter the crystalline configuration and phase transitions favorable to render antimicrobial properties [11,12]. Our study results indicated the presence of silver in all samples with prominent peaks due to the crystalline nature of silver, in addition to strong vibration of silica and blended phosphate vibrations, despite being a non-homogenized preparation. Calcium silicate as well as calcium carbonate diffraction peaks were observed through the XRD patterns. After the impregnation of silver, the noise peaks turned into sharp peaks due to the crystalline nature of silver. Sharp peaks are indicative of strong vibration of silica and blended phosphate vibration. After the addition of AgNPs, all three samples exhibited a decrease in intensity in carbonate peaks both in XRD as well as FT-IR. AgNPs caused a reduction of carbonate peak intensity both in XRD as well as FT-IR due to potential interaction or interference between the AgNPs and the carbonate molecules. Adsorption of carbonate ions to the surface of AgNPs resulted in reduced availability for the detection of carbonate molecules during analysis. This adsorption process may change the vibrational or diffractive characteristics of the carbonate ions, thus decreasing their intensities at peaks. Additionally, distinct silica and phosphate vibrations and the presence of intense crystalline peaks indicate a significant impact of AgNPs on the crystal structure of the samples. These characteristics of AgNPs in the presence of calcium-based composites are similar to other studies, irrespective of the method of synthesis [18]. Further, results were also indicative of the changes in the crystal configuration in terms of lattice parameters, crystal morphology, or orientation, suggestive of an intricate interplay between AgNPs and MTA matrix leading to fundamental re-arrangement of the crystal lattice. Calcium silicate and calcium carbonate diffraction peaks in the XRD patterns could be ascribed to a crystalline phase transition due to a complex molecular interaction between the AgNPs and the MTA matrix. AgNPs do not show changes in crystalline configuration with minimal concentration; prominent alterations are due to the higher concentration in the prepared admixture [19].

Structural changes evidenced by SEM revealed a rod-like morphology of MTA. The addition of spherical-shaped AgNPs resulted in an alteration of rod orientation with flake-like morphology. In most samples, MTA explicated a rod-like morphology. The morphology has an impactful role in the mineralization and durability of the restoration. It is hypothesized that, along with mineral components, crystal structure plays an enormous role in tubule occlusion. MTA sealers predominantly exhibit rod-like morphology addition of AgNPs resulted in an alteration of rod orientation with flake-like morphology. The rods attached to the flakes of AgNPs were observed at all angles. Complete adherence of rods to the particles is ascribed to the nominal size of the rod-like structure [11]. The transformation from a rod-like to a flake-like morphology in MTA involves intricate molecular-level changes that influence crystal growth. The incorporation of AgNPs may modify the nucleation kinetics, crystallographic orientations, or surface energies, thereby influencing the formation of flake-like structures with a different molecular arrangement [19].

AgNPs have a profound hydroxyl radical scavenging ability, due to a high surface area to volume ratio, favoring interaction with free radicals. Antioxidant activity was evident in all samples with AgNPs. This substantiates the advantage of enhanced ability to scavenge hydroxyl radicals and increase the probability of interactions with free radicals. This characteristic is beneficial in the management of inflammatory environments that persist in periapical infections [16]. Additionally, AgNPs also have the prowess to augment the efficacy of other antioxidants to provide a synergistic effect, which is crucial in the regulation of oxidative stress. However, studies also indicate that antioxidant efficacy can vary with different formulations [20]. Variations in antioxidant activity among the MTA types were observed in the study. MTA White exhibited improved efficacy when

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compared to other products; however, the differences were minimal. This could be attributed to the similar composition of the key ingredients like calcium silicate, bismuth oxide, calcium sulfate, and calcium hydroxide.

These findings underscore the potential clinical applications of AgNPs in dental and biomedical fields, where oxidative stress is implicated in inflammation and tissue damage. Importantly, when used at appropriate concentrations, AgNPs display favorable biocompatibility, making them suitable for medical applications without adversely affecting cell viability. Together, these attributes position AgNPs as valuable components in formulations aimed at combating oxidative stress and promoting health.

The incorporation of AgNPs into the MTA matrix confers several benefits, like enhanced antioxidant properties, improved sealing ability, potentially enhanced bioactivity, and sustainability [18]. The sustained release of calcium and hydroxyl ions from the MTA-AgNPs admixture is expected to promote a favorable microenvironment for tissue regeneration and antimicrobial activity [9]. However, the incorporation of AgNPs into the MTA matrix may also pose potential challenges, such as the potential impact on the material's physical and mechanical properties, as well as the possible cytotoxic effects of AgNPs at high concentrations [20]. Therefore, a careful balance between the benefits and the biocompatibility of the MTA-AgNPs admixture must be established through comprehensive *in vitro* and *in vivo* evaluations.

CONCLUSIONS

The structural and morphological characterization of AgNPs-intruded MTA admixture as a chairside restorative medicament holds promise for enhanced antioxidant properties, improved clinical outcomes, and sustainability. However, further research is needed to optimize the formulation and ensure the safety and efficacy of this novel MTA-based material.

CONFLICT OF INTEREST

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

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AUTHOR CONTRIBUTIONS

Conceptualization: Ramadoss R, Rao HM, Krishnan R. Data curation, Investigation, Methodology: Ramadoss R, Shivalingam C. Formal analysis, Software, Validation: Shivalingam C. Visualization, Resources: Rao HM. Project administration, Supervision: Krishnan R. Writing - original draft: Ramadoss R. Writing - review & editing: Rao HM, Ramadoss R. All authors read and approved the final manuscript.

DATA SHARING STATEMENT

The datasets are not publicly available but are available from the corresponding author upon reasonable request.

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Case Report

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Multidisciplinary management of an endo-perio lesion complicated by a cemental tear: a case report

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ABSTRACT

Endodontic-periodontal lesions (EPLs) complicated by cemental tears present a diagnostic and therapeutic challenge. This case report describes the successful management of a 66-year-old male patient with a mandibular second molar (#18) exhibiting an EPL complicated by a cemental tear. Clinical examination revealed a draining sinus tract, deep periodontal pockets, and radiographic evidence of a "J-shaped" lesion and a radiopaque cemental fragment. The tooth had previously initiated endodontic treatment. A multidisciplinary approach involving endodontic treatment and surgical removal of the cemental tear was implemented. At 24-month follow-up, clinical and radiographic examination revealed significant improvement in periodontal health, bone regeneration, and resolution of the lesion. This case highlights the importance of considering cemental tears in the differential diagnosis of EPLs and demonstrates the efficacy of a combined endodontic-periodontal approach for achieving predictable outcomes.

Keywords: Dental cementum; Endodontics; Periodontal diseases; Periodontics; Root canal therapy; Tooth fractures

INTRODUCTION

Endodontic-periodontal lesions (EPLs) present complex challenges in dental practice due to their multifaceted etiology and pathogenesis. These lesions involve both pulpal and periodontal tissues, often necessitating a multidisciplinary approach for effective diagnosis and treatment [1]. The intricate relationship between endodontic and periodontal tissues is facilitated by various anatomical pathways, including dentinal tubules, lateral and accessory canals, and apical foramina [1].

Cemental tears, a unique form of root surface fracture, can further complicate the diagnosis and management of EPLs. Defined as the partial or complete detachment of cementum from the cemento-dentinal junction or along incremental lines within the cementum, cemental tears are often overlooked or misdiagnosed [2]. Their presence can lead to rapid localized periodontal break-

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down and may mimic or exacerbate EPLs [3].

The prevalence of cemental tears is reported to be lower than 2%, with a higher incidence in incisors (74%) and on interproximal surfaces (79%) [3]. Predisposing factors for cemental tears include age-related changes, occlusal trauma, and periodontal disease [4]. The diagnosis of cemental tears is challenging, as they often present with clinical and radiographic features similar to primary endodontic diseases, primary periodontal diseases, or combined EPLs [3].

Treatment of EPLs complicated by cemental tears requires a comprehensive approach. While primary endodontic lesions can often be managed with endodontic treatment alone, cases involving cemental tears typically necessitate both endodontic and periodontal therapies [5]. Management strategies may include non-surgical periodontal treatment, surgical debridement, and in some cases, regenerative procedures [2,5].

This case report highlights the successful diagnosis and management of a mandibular second molar with an EPL complicated by a cemental tear. By presenting this case, we aim to increase awareness of cemental tears among dental professionals and demonstrate the importance of accurate diagnosis and multidisciplinary treatment planning in managing these complex cases [3–5].

CASE REPORT

A 66-year-old male patient with an unremarkable medical history and blood pressure of 128/72 mmHg was referred to the endodontist for root canal therapy on tooth #18 (or 37 according to FDI [Fédération Dentaire Internationale] numbering system) by the general dentist. The patient reported that the general dentist had attempted endodontic treatment on the tooth 3 months ago, following which the tooth had been asymptomatic. However, since 2 weeks, the patient had started to experience persistent pain upon biting and chewing.

Clinical examination revealed a large mesial-occlusal-distal composite restoration with #18, which had an endodontic access temporized with a temporary restoration. A draining sinus tract was noted distal to tooth #18, with periodontal probing depths of 3-4-12 (buccal) and 3-4-6 (lingual). Tooth #18 exhibited Miller's Grade I mobility. It was nonresponsive to cold and tender to percussion and palpation. Tooth #19 had an extracoronal gold restoration, was responsive to cold, and not tender to percussion (Table 1).

Radiographically, a "J-shaped" lesion was observed along the distal root of #18 (Figure 1), suggestive of a primary endodontic lesion with secondary periodontal involvement. A radiopaque fragment, consistent with a cemental tear, was identified along the distal root surface (Figure 1).

Based on the clinical and radiographic findings, a diagnosis of previously initiated therapy with chronic apical abscess was reached for #18. Owing to the advanced periodontal bone loss and deep pockets, a poor prognosis was expected for #18. The patient was informed of the findings and given the options of a multidisciplinary approach combining endodontic treatment and periodontal therapy or an alternative of extraction and prosthodontic replacement. Motivated to preserve his natural dentition, the patient opted for the conservative multidisciplinary treatment plan.

After administering two cartridges of 2% lidocaine with 1:100,000 epinephrine (Patterson Dental, St. Paul,

Table 1. Endodontic sensibility testing chart

Test	Tooth number				
	#18	#19	#20	#31	#15
Cold	–	+	+	+	+
Percussion	++	–	–	–	–
Palpation	++	–	–	–	–
Periodontal probing	B: 3, 4, 12 L: 3, 4, 6	B: 3, 3, 3 L: 3, 3, 3	B: 3, 2, 3 L: 3, 2, 3	B: 4, 3, 3 L: 3, 3, 3	B: 3, 3, 4 L: 3, 3, 3
Mobility*	I	I	I	I	I

B, buccal; L, lingual.
*Miller's Classification.

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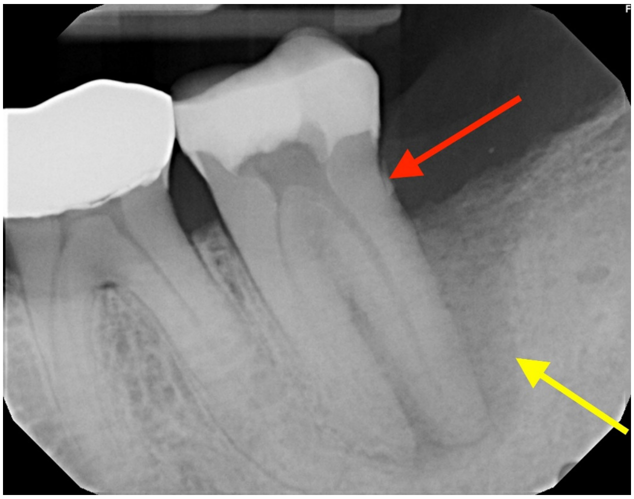

Figure 1. "J-shaped" lesion observed along the distal root of #18 (yellow arrow). A radiopaque fragment, consistent with a cemental tear, was identified along the distal root surface (red arrow).

MN, USA) as an inferior alveolar nerve block and a half cartridge as local infiltration, a rubber dam was placed for isolation. Upon access, necrotic pulp was encountered, and the pulp chamber of #18 was examined under a dental operating microscope. The absence of fractures was confirmed with methylene blue dye, and three canals (mesiobuccal, mesiolingual, and distal) were located.

Working lengths were determined using an electronic apex locator (RootZX; J Morita, Kyoto, Japan) and confirmed with a periapical radiograph, which also showed a radiopaque fragment consistent with a cemental tear (Figure 2). The chamber was flooded with 5% sodium hypochlorite, and the canals were instrumented using size 8, 10, 15, and 20 K files, followed by a 25/.07 Primary Wave One Gold (Dentsply Sirona, Charlotte, NC, USA) reciprocating file. Irrigation was performed with 12 mL of 5% sodium hypochlorite with ultrasonic activation for 30 seconds per canal. Calcium hydroxide was placed as an intracanal medicament with a lentulo spiral, and the tooth was temporized with a sterile sponge and Cavit (3M ESPE, St. Paul, MN, USA). The patient was informed to return in 2 weeks for completion of the root canal.

At the 2-week follow-up, the sinus tract had healed. After the same anesthesia and isolation protocol as the first visit, the tooth was accessed through the temporary restoration. Calcium hydroxide was irrigated out with

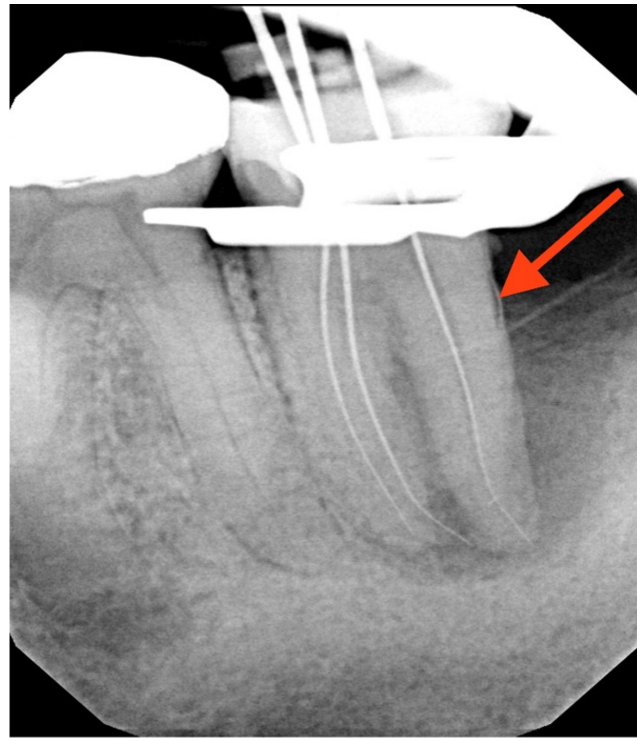

Figure 2. Working length radiograph showing radiopaque fragment consistent with a cemental tear along distal root (red arrow).

17% ethylenediaminetetraacetic acid solution, which was ultrasonically activated for 15 seconds in each canal. This was followed by 5% sodium hypochlorite irrigation, which was ultrasonically activated for 15 seconds in each canal, after which cone fit was verified clinically and confirmed with a radiograph (Figure 3). The canals were then dried with paper points, and obturation was completed using gutta-percha cones and AH Plus sealer (Dentsply DeTrey GmbH, Konstanz, Germany) with the cold lateral condensation technique. The tooth was temporized with a sterile sponge and Cavit (3M ESPE) and a postoperative radiograph was captured (Figure 4). A referral for periodontal therapy was given to the patient.

The patient reported for the periodontal treatment after 2 months. At this time, periapical radiograph (Figure 5) indicated reduced periapical radiolucency, but the radiolucency on the distal aspect of the distal root persisted. The tooth was nontender to percussion, but an 11 mm pocket was present along the distal-buccal line angle.

The same protocol of local anesthesia was adminis-

Figure 3. Cone-fit radiograph.

Figure 4. Immediate postoperative radiograph.

tered, and a full-thickness flap was raised by placing a sulcular incision with a vertical release mesial to #20 and a crestal incision distal to #18. Scaling and root planing were performed on teeth #18, #19, and #20. The cemental tear fragment was curetted and removed. The surgical site was closed with five interrupted mattress sutures with 4-0 chromic gut sutures. Hemostasis was confirmed. Postoperative instructions were provided, and the patient was scheduled for follow-up visits at 1 month, 3 months, and 9 months.

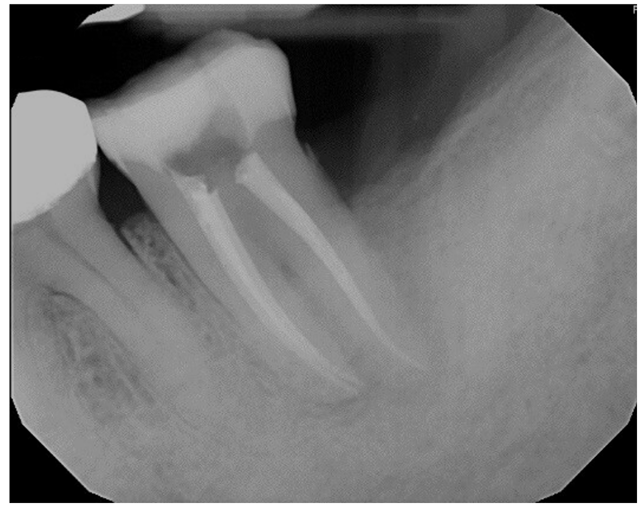

Figure 5. Periapical radiograph at 2 months indicating reduced size of periapical radiolucency and persistent radiolucency along the distal aspect of the distal root.

The patient was lost to follow-up until he reported again at 24 months, at which time clinical examination revealed that a full-coverage restoration on tooth #18 had been placed, restoring form and function (Figure 6). Clinical gingival health was noted on a reduced periodontium. Draining sinus tract remained resolved, and probing depths were improved to 3–4 mm. The tooth exhibited no mobility. Periapical radiograph (Figure 7) showed significant resolution of the periapical radiolucency with substantial bone regeneration along the length of the distal root. The patient was greatly appreciative that his natural dentition was conserved, which motivated him to ensure continued dental care maintenance.

DISCUSSION

The successful management of EPLs complicated by cemental tears requires a thorough understanding of their etiology, diagnosis, and contributing factors to treatment success. Cemental tears, though relatively rare,

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Figure 6. Twenty-four-month recall showing that the tooth has been restored with an extracoronal restoration and absence of draining sinus tract. Gingival health on a reduced periodontium is noted.

Figure 7. Periapical radiograph showed significant resolution of the periapical radiolucency with substantial bone regeneration along the length of the distal root.

play a significant role in periodontal breakdown and are often misdiagnosed, leading to progressive disease and treatment challenges. Their etiopathogenesis is multifactorial, involving age-related structural changes, occlusal trauma, and periodontal disease, which weaken the attachment between cementum and dentin, resulting in fragmentation [6,7]. The prevalence of cemental tears remains low, affecting less than 2% of teeth, with a higher incidence in maxillary and mandibular incisors, particularly on interproximal surfaces [8]. Their presence can mimic primary periodontal or endodontic lesions, making an accurate differential diagnosis crucial.

Differentiating cemental tears from other endodontic or periodontal pathologies requires a combination of clinical, radiographic, and histologic evaluations. Clinically, cemental tears present as isolated deep periodontal pockets, persistent inflammation despite treatment, and mobility in affected teeth [2,7,9]. Radiographically, a radiopaque fragment adjacent to the root surface, particularly in cases with rapid localized periodontal destruction, should raise suspicion [9]. Cone-beam computed tomography can enhance diagnostic accuracy, providing detailed three-dimensional imaging of root surfaces and periodontal defects [10]. In the present case, the presence of a "J-shaped" radiolucency along the distal root and a small radiopaque fragment was suggestive of a cemental tear contributing to the persistent periodontal involvement.

The treatment strategy for EPLs complicated by cemental tears requires a multidisciplinary approach, as endodontic treatment alone is often insufficient. While primary endodontic lesions can typically be resolved with thorough root canal disinfection, intracanal medication, and obturation, cases involving cemental tears necessitate periodontal intervention to remove the fragmented cementum and facilitate healing [11–13]. Periodontal therapy, including surgical debridement and root surface conditioning, improves treatment outcomes by reducing pocket depth and promoting periodontal reattachment [14]. The use of regenerative techniques, such as guided tissue regeneration and biologic mediators, may further enhance periodontal healing in select cases [6].

Factors contributing to the success of treatment include early diagnosis, complete removal of necrotic cementum, and patient compliance with periodontal maintenance. The ability of periodontal tissues to regenerate is influenced by the severity of attachment loss and bacterial contamination at the affected site [15].

In this case, the combination of thorough endodontic treatment, surgical removal of the cemental fragment, and postoperative monitoring contributed to significant periodontal improvement and radiographic evidence of bone regeneration. At twenty-four months, probing depths had returned to a healthy range, and the patient was asymptomatic, highlighting the effectiveness of an interdisciplinary approach.

This case underscores the importance of recognizing cemental tears as a potential complicating factor in EPLs. A misdiagnosis or delayed intervention can lead to rapid periodontal deterioration, ultimately resulting in tooth loss [16]. Advanced imaging modalities, combined with a collaborative approach between endodontists and periodontists, can optimize treatment planning and long-term outcomes [17]. By increasing awareness of cemental tears and their management, clinicians can improve diagnostic accuracy and enhance treatment success in these challenging cases.

CONCLUSIONS

Effective management of EPLs complicated by cemental tears requires a multidisciplinary approach. Cemental tears, though rare, can complicate diagnosis and treatment, often mimicking other pathologies. This case demonstrates the importance of early diagnosis and intervention, utilizing both endodontic and periodontal therapies to achieve favorable outcomes. Through comprehensive treatment and careful monitoring, significant improvement in periodontal health and bone regeneration was achieved. Recognizing cemental tears as a complicating factor in EPLs can help clinicians improve diagnostic accuracy and treatment success in these complex cases.

CONFLICT OF INTEREST

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

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AUTHOR CONTRIBUTIONS

Conceptualization, Supervision: Oza S. Data curation, Methodology: Sadhak ND. Software: Pallod A. Writing - original draft: Sadhak ND, Pallod A. Writing - review & editing: Oza S. All authors read and approved the final manuscript.

DATA SHARING STATEMENT

The datasets are not publicly available but are available from the corresponding author upon reasonable request.

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