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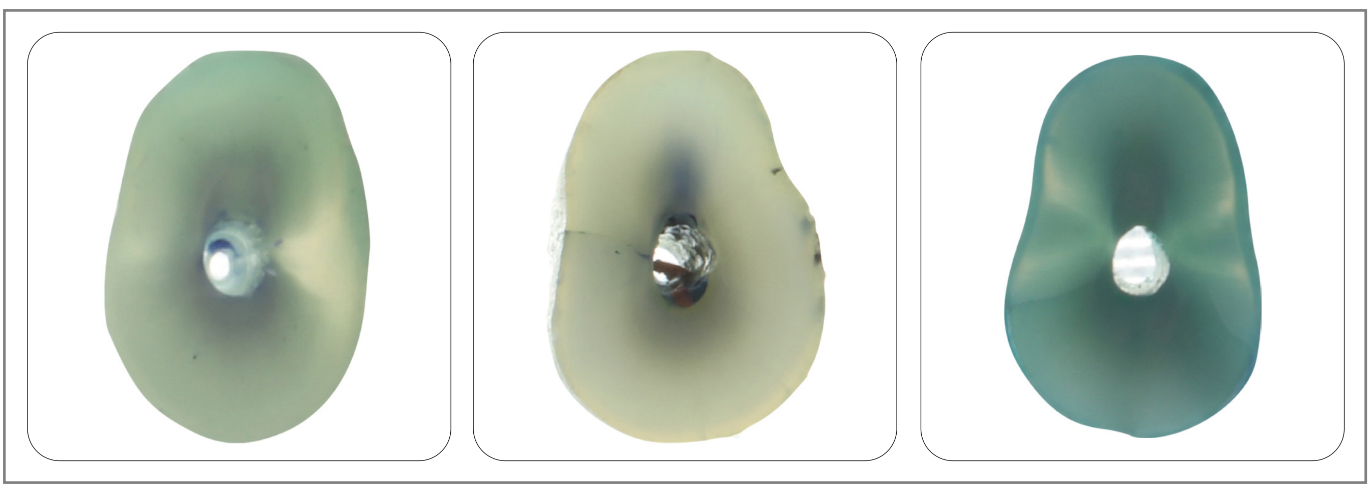

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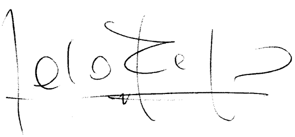

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Editorial

Endodontics and Systemic Health: A Clinical Responsibility Beyond the Tooth

For many years, endodontics has been perceived primarily as a discipline devoted to the preservation of the dental element. Today, however, the growing attention to the relationship between oral health and systemic health requires a broader perspective: the management of endodontic infections concerns not only the prognosis of the individual dental element, but may also have relevant implications for the patient's overall health.

Scientific literature in recent years has highlighted how odontogenic infections may represent a potential source of bacteremia and systemic microbial dissemination. Invasive dental procedures, including endodontic treatments, can lead to the passage of microorganisms into the bloodstream and, in susceptible individuals, these bacteria may colonize cardiovascular structures or implanted medical devices, contributing to the development of serious infectious complications. Among these, infective endocarditis remains one of the most worrying conditions, characterized by bacterial colonization of the endocardium and heart valves and associated with significant morbidity and mortality.

Moreover, increasing evidence suggests a correlation between dental disease—including lesions of endodontic origin—and cardiovascular disease. Several studies have reported a higher prevalence of caries, endodontic lesions and edentulism in patients with ischemic heart disease, suggesting that chronic inflammation of oral origin may represent a risk factor or a contributing element in the systemic disease process.

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Two papers presented in the present issue of the Italian Endodontic Journal fit precisely within this broader clinical perspective. The contributions dedicated to patients with cardiovascular disease and to those with implantable medical devices highlight how endodontic management should be planned by considering not only local variables—such as root canal anatomy, microbiology and operative techniques—but also the patient's systemic risk profile. Careful medical history assessment, knowledge of guidelines on antibiotic prophylaxis in high-risk subjects and interdisciplinary collaboration therefore become essential elements of clinical practice. The treatment of dental infections and the control of oral inflammation today represent not only an oral objective but also a concrete contribution to the protection of the patient's systemic health. From this perspective, endodontics is not merely the discipline that saves the tooth, but also the one that contributes to protecting the patient as a whole.

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ORIGINAL ARTICLES

Comparison of root dentin damage induced by three techniques for cast post removal

ABSTRACT

Aim: *To investigate root dentin defects induced by different cast post removal techniques.*

Methodology: *One hundred bovine incisors were standardized to 15 mm. Twenty roots served as unprepared controls; the remaining 80 were instrumented with the BioRace system (to size 40/.04), obturated using lateral condensation, and prepared for post space with #1-4 Largo drills. Of these, 60 received directly fabricated cast posts cemented with zinc phosphate. Post removal was performed using ultrasonic vibration, a carbide bur, or a spring-activated device. Roots were sectioned at 4, 8 and 12 mm from the apex and examined at 25× magnification to assess the presence of fractures and other dentinal defects (partial cracks and craze lines). Data were analyzed with the Chi-square test (α = 0.05) and Bonferroni-adjusted pairwise z-tests.*

Results: *Among 300 sections, 103 (34.3%) showed defects. The control group showed none. All removal techniques produced defects, with no significant difference among protocols for other defects ($P>0.05$). The spring-activated device was associated with a higher number of root fractures ($P<0.05$). Defects distribution was similar across root levels (4, 8 and 12 mm).*

Conclusions: *All techniques caused dentin damage. Only the spring-activated device increased fractures. Careful selection of the removal strategy is advised.*

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Introduction

Signs of root canal treatment failure, such as persistent periapical radiolucency or associated clinical symptoms, typically signal the need for additional intervention (1). These indicators are often related to microbial persistence that surpasses host defense mechanisms (2-4). In teeth restored with cast metallic posts, such conditions are not uncommon (2), and necessitate nonsurgical endodontic retreatment (1). A crucial step in such procedures is the unobstructed access to the root canal system, which requires effective and safe post removal (5, 6).

A variety of techniques and devices are available for dislodging intraradicular posts, including spring-activated traction systems, carbide burs, and ultrasonic devices (5, 7, 8). Carbide burs work by abrading the post material (5), whereas ultrasonic devices use high-frequency vibrations to break the bond between post and dentin (9, 10). Spring-activated systems apply axial traction to extract the post mechanically (11).

Endodontic and restorative procedures, including root canal preparation, filling, retreatment, and post space preparation, have been shown to cause structural changes in root dentin (12-15). These alterations can serve as precursors to vertical root fractures, threatening the long-term prognosis of treated teeth (16). Nevertheless, there is limited evidence regarding the formation of such defects specifically following post removal (6, 7, 17, 18). To date, the mechanical effects of removing cast metal posts with carbide burs or spring-loaded systems have not been thoroughly investigated.

Therefore, the present study evaluated the occurrence of root dentin defects after cast post removal using ultrasonic vibration, carbide burs and a spring-activated device. The tested null hypotheses were that (i) the type of post removal technique would not influence the occurrence of root fractures or other dentinal defects, and (ii) these outcomes would not vary across different root levels.

Materials and Methods

Sample size calculation

The sample size was determined based on previously reported effect sizes for dentinal defects caused by post space preparation drills (19) and ultrasonic removal methods (7). Using G* Power software (version 3.1.2; Heirich Heine, Universität Düsseldorf, Düsseldorf, Germany), with $\alpha = 0.05$ and power $(1-\beta) = 0.80$, the minimum requirement was calculated as 12 samples per group.

Sample selection and preparation

One hundred bovine incisors with complete root formation and similar morphology were selected. Preoperative radiographs (buccolingual and mesiodistal) confirmed comparable root canal widths and straight configurations (6, 19). Teeth presenting anatomical anomalies, excessive curvature, or calcifications were excluded.

Coronal portions were removed using a diamond disc (KG Sorensen, São Paulo, SP, Brazil) perpendicular to the tooth's long axis, yielding a standardized root length at 15 mm. Under 20× magnification (Expert DN; Müller Optronic, Erfurt, Germany), roots were inspected for cracks or surface defects. Any root showing preexisting damage was discarded and replaced.

To simulate the periodontal ligament, each root was coated with a silicone impression material (Aquasil; Dentsply Maillefer, Ballaigues, Switzerland) before embedding in acrylic resin blocks (6, 20). Twenty roots were left unprepared as negative controls (Group 1), while the remaining 80 roots underwent canal instrumentation, obturation and post space preparation.

Instrumentation and obturation

Canal patency was confirmed with a #10 K-File (Dentsply Maillefer, Ballaigues, Switzerland). Roots allowing passage of files larger than ISO #15 K-File (Dentsply Maillefer, Ballaigues, Switzerland) were replaced (21). All roots were instrumented to a working length (WL) of 14 mm (1 mm short of the apex) using a crown-down technique with the BioRace rotary system (FKG Dentaire, La Chaux-de-Fonds, Switzerland) operated by a torque- and speed-controlled motor (X-Smart Plus; Dentsply Maillefer, Ballaigues, Switzerland), using the following sequence: BR0 (#25/.08), BR1 (#15/.05), BR2 (#25/.04), BR3 (#25/.06), BR4 (#35/.04), and BR5 (#40/.04) as the master apical file. Each instrument was used for the preparation of five root canals and was operated at a rotational speed of 600 rpm and 1.5 N/cm torque.

Irrigation was carried out with 3 mL of 2.5% sodium hypochlorite (NaOCl; Pharm, Phloraceae, Cuiabá, MT, Brazil) between each file using a 31-gauge NaviTip needle (Ultradent, South Jordan, UT, USA) positioned 1 mm short of the WL with gentle up-and-down motion, avoiding binding. Final irrigation comprised 3 mL of 17% EDTA (Biodinâmica, Ibiporã, PR, Brazil) for 3 min, followed by 3 mL of 2.5% NaOCl (Pharm, Phloraceae, Cuiabá, MT, Brazil). Irrigating solutions were used at room temperature without activation. All roots were re-examined under 20× magnification (Expert DN; Müller Optronic, Erfurt, Germany), and no defects were detected.

Before obturation, canals were dried with sterile paper points (Dentsply Maillefer). Lateral condensation was used for obturation with a gutta-percha master cone (Dentsply Maillefer, Ballaigues, Switzerland) and Sealapex sealer (SybronEndo, São Paulo, SP, Brazil), which was mixed according to the manufacturer's instructions. Accessory cones were inserted with a size B spreader (Dentsply Maillefer, Ballaigues, Switzerland). The coronal excess was removed with heated instruments and sealed with temporary restorative material (Vidrion R; SS White, Rio de Janeiro, RJ, Brazil). Radiographs confirmed the obturation quality. Roots were stored at 37°C and 100% humidity for one week to ensure complete setting of the sealer.

Post space preparation and cementation

After removal of the temporary material, a 10-mm post space (measured from the cervical surface) was created, preserving a 4-mm apical seal. Gutta-percha was initially removed with flame-heated vertical condensers. Subsequently, #1-4 Largo drills (Dentsply Maillefer, Ballaigues, Switzerland) were used sequentially to refine the post space. Canals were irrigated with 3 mL of 2.5% NaOCl (Pharm, Phloraceae, Cuiabá, MT, Brazil) after each drill change and dried with sterile paper points (Dentsply Maillefer, Ballaigues, Switzerland).

Twenty roots remained with only post space preparation (Group 2). For the other 60 roots, cast posts were fabricated using a direct technique with acrylic resin (Duralay; Reliance Dental, Worth, IL, USA) and polycarbonate posts (Pinjet; Angelus, Londrina, PR, Brazil). Patterns were standardized to 4 mm coronal height, cast in copper-aluminum alloy (Goldent L.A.; Comercial Importação e Exportação, São Paulo, SP Brazil), sandblasted with aluminum oxide, and adjusted (6).

Zinc phosphate cement (SS White, Rio de Janeiro, RJ, Brazil) was used for luting, applied with a lentulo-spiral (Dentsply Maillefer, Ballaigues, Switzerland). Finger pressure was maintained for 1 minute. Excess cement was removed, and roots were stored again at 37°C and 100% humidity for one week. These 60 specimens were allocated into three experimental groups (n = 20), by a computer-generated randomization list, each subjected to one of the post removal methods.

Ultrasonic vibration (group 3)

The coronal part of each post was reduced using a #3069 bur (KG Sorensen, São Paulo, SP, Brazil) (6). Ultrasonic

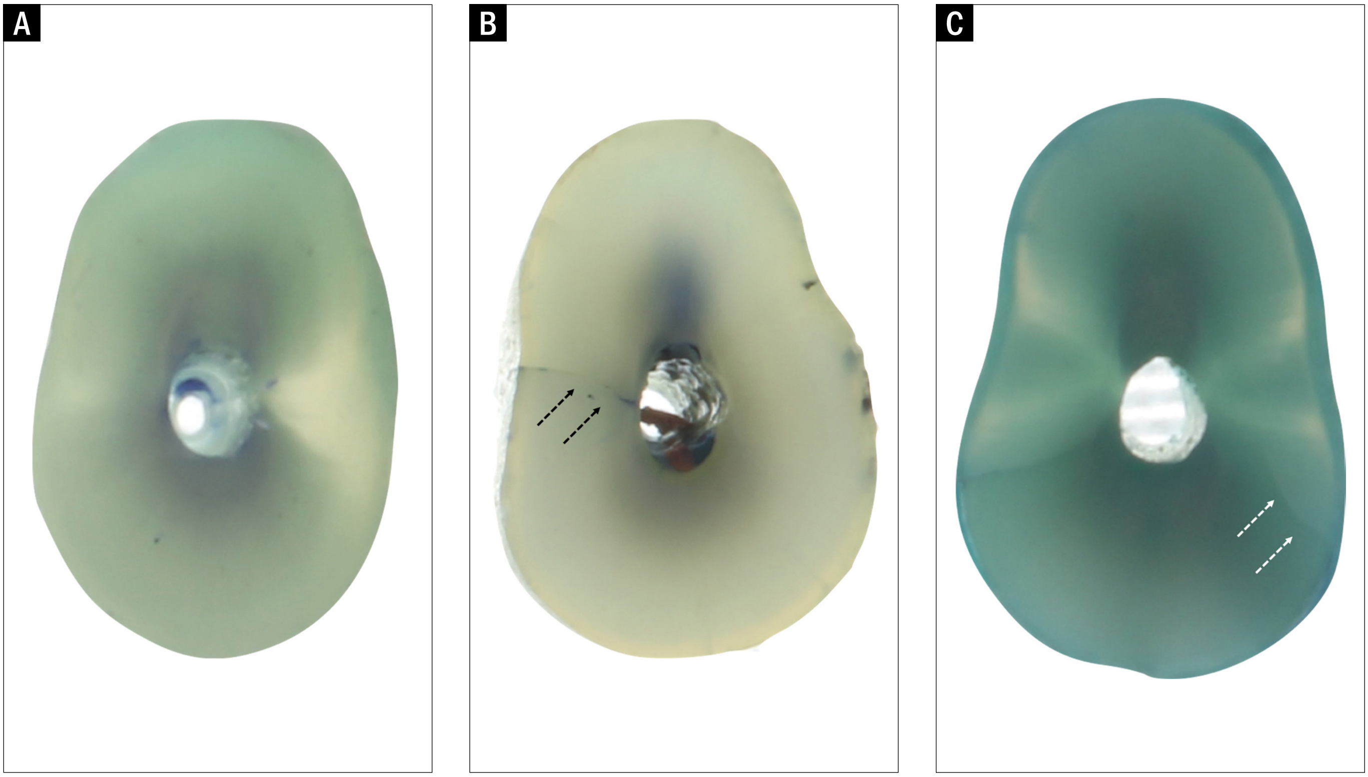

Figure 1
Representative images of root slices **(A)** Root slice without defects. **(B)** Root slice showing a root fracture (black arrows). **(C)** Root slice showing a partial crack (white arrows)

vibration was applied using an EMS PM 200 ultrasonic unit (EMS - Electro Medical Systems S.A., Nyon, Switzerland) and E12 tip (Helse Ultrasonic, Santa Rosa de Viterbo, SP, Brazil). The tip was placed perpendicularly at the cervical margin (10), and activated at 80% power with continuous water cooling for 1 minute on each surface (buccal, lingual, mesial and distal), totaling 4 minutes per tooth (6). Post removal was confirmed visually and radiographically.

Carbide bur (group 4)
Post removal was performed by mechanical wear using a #1/2 carbide bur (Dentsply Maillefer, Ballaigues, Switzerland), ensuring that the bur remained in contact exclusively with the post and avoiding contact with the surrounding tooth structure. Wear progression in the apical direction was monitored radiographically, with images taken at multiple angulations. The post was considered completely removed when no remnants were visible in the radiographs. The carbide bur was replaced after every five post removal (11).

Spring-activated device (group 5)
Small horizontal grooves, approximately 1 mm deep, were created on the buccal and lingual surfaces of the coronal portion of the post using a #1/2 carbide bur (Dentsply Maillefer, Ballaigues, Switzerland), allowing proper adaptation and fixation of the traction tip. After adjusting the spring pressure to level 1, the traction tip was inserted into the groove, and the spring-activated device (Otto Metalúrgica Arminger, São Paulo, SP, Brazil) was positioned parallel to the long axis of the post. The removal force was applied by pressing the device's trigger, releasing the internal spring mechanism to generate the extraction force (11). The roots were then inspected visually and radiographically to ensure complete post.
Throughout the procedures, all samples were kept moist in distilled water to prevent dehydration. One endodontist

and one oral rehabilitator, both with more than 10 years of experience, performed all clinical procedures.

Sectioning and microscopic evaluation

Each root was removed from the resin block, and the silicone layer was detached. Roots were horizontally sectioned at 4, 8 and 12 mm from the apex using a double-faced diamond disc (4" diameter × 0.012" thickness × 1/2"; Arbor, Extec, Enfield, CT, USA) mounted on a precision saw (Isomet 1000, Buehler, Lake Bluff, IL, USA), with water cooling. Sections were dried and stained with 1% methylene blue (Pharm, Phloraceae, Cuiabá, MT, Brazil) for defect visualization (21). Slices were examined under 25× magnification (Expert DN; Müller Optronic, Erfurt, Germany). Digital images were analyzed and classified into three categories (12). "No defect" was defined as the absence of any lines or cracks on both the internal canal walls and external root surface. "Fracture" was defined as a crack extending from the root canal lumen to the external root surface. "All other defects" included all other visible lines, such as: partial cracks (extending from the root canal wall into the dentine without reaching the external surface) and craze lines (extending from the outer surface into the dentin without contact the canal lumen) (Figure 1 A to C).
A total of 60 images were analyzed in each group. All assessments were performed by a previously calibrated, blinded examiner. Each image was assessed twice, with a one-week interval.

Statistical analysis

The frequency of defects was expressed as counts and percentages for each group. Data were analyzed using IBM SPSS for Windows, version 21.0 (IBM Corp., Armonk, NY, USA). Chi-square test was used to compare groups and assess differences across root levels (4, 8 and 12 mm). Significance was set at $P<0.05$. Bonferroni-adjusted z-tests were used for pairwise comparisons. Intraexaminer reliability was calculated using kappa statistics based on 10% of the samples.

Results

The kappa coefficient obtained for intraexaminer agreement was 0.87, indicating excellent reliability in the evaluation of dentin defects.
Among the 300 sections examined, 103 (34.3%) exhibited structural alterations in root dentin (Tables 1 and 2). The vast majority of these defects (n = 94; 91.2%) were classified as either partial cracks or craze lines. The control group (Group 1) showed no evidence of defects at any assessed level.
In Group 2, which included specimens subjected to instrumentation, obturation, and post space preparation without post insertion, a small number of fractures were observed (Table 1). When comparing this with the experimental groups (Groups 3 to 5), a statistically significant increase in root fractures was identified only in the group where spring-activated device was employed ($P = 0.007$) (Table 1). Statistically significant differences in fracture incidence were also found among the three cast post removal techniques ($P<0.05$) (Table 1).
Regarding other types of dentin defects (partial cracks and craze lines), all post removal groups demonstrated a higher number of occurrences compared to group 2, although these differences did not reach statistical significance. Additionally, no significant variation in defect frequency was observed when comparing the three post removal protocols with each other ($P>0.05$) (Table 2).
With respect to root level distribution (4, 8 and 12 mm from the apex), there were no statistical significance differences in the incidence of root fractures ($P = 0.357$) or other types of defects ($P = 0.323$) (Tables 1 and 2). However, a higher absolute number of defects was

Groups	Root level			Total	P value*
	12 mm	8 mm	4 mm		
G1	0 (0.0%)^{A,a}	0 (0.0%)^{A,a}	0 (0.0%)^{A,a}	0 (0.0%)^{A}	>0.05
G2	1 (11.1%)^{A,a}	0 (0.0%)^{A,a}	0 (0.0%)^{A,a}	1 (11.1%)^{A}	0.362
G3	2 (22.2%)^{A,a}	0 (0.0%)^{A,a}	0 (0.0%)^{A,a}	2 (22.2%)^{A}	0.126
G4	0 (0.0%)^{A,a}	0 (0.0%)^{A,a}	0 (0.0%)^{A,a}	0 (0.0%)^{A}	>0.05
G5	1 (11.1%)^{A,a}	4 (44.4%)^{A,b}	1 (11.1%)^{A,a}	6 (66.7%)^{B}	0.189
Total	4 (44.4%)^{a}	4 (44.4%)^{a}	1 (11.1%)^{a}	9 (100%)	0.357
P Value*	0.456	0.002	0.401	0.007	

*Chi-square test. G1: Negative control; G2: Instrumentation, obturation and post space preparation; G3: Ultrasonic vibration; G4: Carbide bur; G5: Spring-activated device. Capital letters compare groups in vertical columns and lower-case letters compare groups in horizontal rows.

Table 1
Distribution of root fractures according to post removal technique and root level.

Groups	Root level			Total	P value*
	12 mm	8 mm	4 mm		
G1	0 (0.0%)^{A,a}	0 (0.0%)^{A,a}	0 (0.0%)^{A,a}	0 (0.0%)^{A}	>0.05
G2	7 (7.4%)^{B,a}	2 (2.1%)^{A,B,a}	6 (6.4%)^{A,B,a}	15 (16.0%)^{B}	0.155
G3	12 (12.8%)^{B,a}	12 (12.8%)^{C,a}	3 (3.2%)^{A,B,b}	27 (28.7%)^{B}	0.004
G4	6 (6.4%)^{A,B,a}	6 (6.4%)^{A,B,C,a}	11 (11.7%)^{B,a}	23 (24.5%)^{B}	0.172
G5	12 (12.8%)^{B,a}	9 (9.6%)^{B,C,a}	8 (8.5%)^{B,a}	29 (30.9%)^{B}	0.420
Total	37 (39.4%)^{a}	29 (30.9%)^{a}	28 (29.8%)^{a}	94 (100%)	0.323
P Value*	<0.001	<0.001	<0.001	<0.001	

*Chi-square test. G1: Negative control; G2: Instrumentation, obturation and post space preparation; G3: Ultrasonic vibration; G4: Carbide bur; G5: Spring-activated device. Capital letters compare groups in vertical columns and lower-case letters compare groups in horizontal rows.

Table 2
Distribution of all other defects according to post removal technique and root level.

recorded in sections obtained at 12 mm and 8 mm (Tables 1 and 2).

Discussion

Endodontic retreatment is usually required because intraradicular infection persists after primary therapy, sustained by biofilms and by limited irrigating solution penetration into complex anatomy (3, 4). In teeth with cast posts, retreatment first demands post removal to re-establish canal access (5, 6). This investigation examined whether different techniques for cast post removal influenced the development of root dentin defects, including root fractures, partial cracks and craze lines. Among the tested protocols - ultrasonic vibration, carbide burs, and a spring-activated device - only the latter demonstrated a statistically significant increase in root fractures. Based on these findings, the initial null hypothesis was partially rejected.

Several methodologies have been proposed for detecting dentin damage during intracanal procedures, such as thermography (22) and scanning electron microscopy (SEM) (20). However, most insights in this field are derived from studies employing either micro-computed tomography (micro-CT) (23-25) or the root-sectioning method (6, 12-14, 19, 21, 26, 27). Micro-CT offers high-resolution, three-dimensional, non-destructive imaging that allows detailed assessment of structural alterations before and after treatment (23-25). Its primary advantages include the capacity for repeated measures on the same specimen (25) and enhanced

visualization of defect propagation (23-25). Nevertheless, the technique is costly, requires specialized equipment (28), and may be subject to dehydration-related artifacts and limitations in spatial resolution (29).
Conversely, root-sectioning allows for direct visualization of dentin integrity at specific levels, with relatively simple execution and minimal data processing (12, 30, 31). It is particularly useful for studies with large sample sizes and provides a practical means of identifying defect initiation and progression (29). Nevertheless, it is destructive (28), offers only two-dimensional snapshots, and evaluates limited root segments (25), increasing the chance of missing defects (23) or failing to determine their exact moment of formation (23, 24). No universally accepted standard currently exists for the evaluation of dentin defects (19), and further methodological refinement remains necessary.
In the present study, all roots were carefully inspected before instrumentation to exclude preexisting damage. While internal cracks not able to be detected on the external surface cannot be completely ruled out, the complete absence of defects in the control group supports the validity of the findings and reinforces that observed alterations were likely induced by the experimental procedures (12, 14, 27). These results are consistent with previous literature that has reported no dentin damage in unprepared or uninstrumented roots (6, 14, 21, 27, 30).
The simulation of periodontal ligament and alveolar socket using silicone material and acrylic resin embedding was adopted to approximate clinical conditions (20, 26, 28, 32, 33). Despite known limitations in mimicking the viscoelastic properties of natural tissues (26, 33), this approach is widely accepted for improving standardization in experimental endodontic research (32). Root specimens were matched for canal diameter at a reference point (9 mm from the apex) to ensure anatomical comparability (32), given the impact of dentin thickness on mechanical resistance stress (34).
Due to ethical and practical limitations associated with sourcing human teeth (35), bovine incisors were used as a substitute. These teeth exhibit similar physical and mechanical characteristics to human dentin (36), particularly when sourced from older animals, and have been validated in prior studies as reliable alternatives for laboratory experimentation in endodontics (6, 19, 36).
Multiple factors related to the design and properties of the instruments have been implicated in the initiation of microcracks, including cross-sectional geometry, alloy composition, heat treatment, cutting efficiency, instrument size and tip design, pitch and taper variations, flute configuration, the number of instruments used, and the kinematics employed during instrumentation (14, 23, 24, 27, 28). In this study, root canal instrumentation was performed using the BioRace Basic Set, which includes six rotary files: BR0 (#25/.08), BR1 (#15/.05), BR2 (#25/.04), BR3 (#25/.06), BR4 (#35/.04) and BR5 (#40/.04). The BioRace system was chosen due to its design features - alternating cutting edges, non-cutting tip, triangular cross-sectional without radial lands, and electrolytic surface treatment - which have been associated with a lower incidence of dentinal defects (25). Notably, the BR0 and BR3 instruments have high tapers (.08 and .06, respectively), and such taper configuration may increase the contact area with canal walls, thereby concentrating stress and potentially contributing to dentinal defect formation (21, 31). Furthermore, the BioRace system operates under continuous rotation (25), requiring a greater number of rotations to complete instrumentation (15). This increase may generate greater friction between the instrument and dentinal walls, which has also been linked to a higher incidence of dentinal damage (15).
It is well established that the irrigating

solutions used during root canal procedures can influence the structural integrity of root dentin (19). High concentrations of sodium hypochlorite (NaOCl) have been associated with reductions in the elastic modulus and flexural strength of dentin, potentially compromising its mechanical properties (15, 37, 38). To reduce these adverse effects, the present study employed 2.5% NaOCl for irrigation, aiming to preserve dentin integrity during both root canal instrumentation and subsequent post space preparation.

Several root canal filling techniques or their modifications have been proposed to enhance the quality of endodontic sealing (12, 37). Among them, lateral condensation of gutta-percha remains one of the most widely used methods methods due to its proven clinical efficacy (31), low cost, and the ability to control the apical extent of the filling mass (31). However, despite its widespread use, this technique has been associated with a high incidence of vertical root fractures (39). Shemesh et al. (12) demonstrated that lateral condensation produced a greater number of dentinal defects compared to non-compaction techniques. Similarly, Capar et al. (31) reported a high frequency of root cracks in teeth filled using cold lateral condensation and warm vertical compaction techniques. The design of the digital spreader and the magnitude of the condensation force have been identified as key factors contributing to the formation of root defects during the lateral condensation technique (39).

Post-space preparation has been shown to contribute to both the formation (19) and propagation (18) of dentinal defects. This may be attributed to the rigidity and dimensions of the burs used during preparation (18, 19). Larger and stiffer instruments tend to engage more root dentin surface, thereby increasing friction, stress concentration, and the likelihood of inducing structural defects (19). In the present study, Largo drills were selected due to their widespread use in clinical practice for post-space preparation (19). Notably, the incidence of dentin defects observed in this study (n = 16; 15.53%) was lower than that reported in previous studies, which ranged from 19.95% to 77% (7, 19), but higher than the 6.66% observed by Serpa et al. (6). These discrepancies may be attributed to variations in post space preparation techniques, the type and dimensions of the posts used, and the depth of post placement (7).

The removal of cast metallic posts in endodontically treated teeth with periapical pathologies remains a challenging clinical procedure (6, 7). Over the years, various techniques and instruments have been developed to improve the safety and efficiency of this intervention (5-8). This study evaluated the incidence of dentinal defects associated with three commonly used cast post removal methods: carbide burs, ultrasonic vibration, and a spring-activated device. The selection of these methods was based on prior reports supporting their clinical effectiveness (6-8, 11). Carbide bur removal is widely used due to its accessibility and effectiveness, working through direct abrasion of the metallic post (8, 11). Ultrasonic techniques, in contrast, apply mechanical energy to transmit vibrations to the posts, thereby weakening or disrupting the cement interface between the post and the root dentin (6, 9). Spring-activated systems function by applying controlled mechanical traction forces to dislodge the post (11).

All tested cast post removal methods resulted in the formation of dentinal defects (Tables 1 and 2). Among the evaluated techniques, the carbide bur group exhibited the lowest number of defects (n = 23; 22.3%). To date, no studies have specifically investigated root dentin damage resulting from the removal of cast posts using carbide burs. However, Campos et al. (8) pointed out a potential drawback of this method, noticing that the abrasion of cast posts composed of copper-aluminum alloy may lead to an increase in temperature, which can be transferred to surrounding dentinal tissues. This thermal rise may promote dentin dehydration and, consequently, the formation of structural defects. Ultrasonic vibration resulted in an intermediate number of defects (n = 29; 28.1%), despite its theoretical advantage of reducing mechanical stress on the tooth structure during post removal. Altshul et al. (7) observed that ultrasonic removal of threaded posts was associated with a high incidence of dentinal defects. Similarly, Satterthwaite and Stokes (17) reported that prolonged ultrasonic application during the removal of zirconium ceramic and stainless-steel posts significantly increased the incidence of root surface cracks. This finding was corroborated by Serpa et al. (6), who observed the occurrence of dentinal defects with the use of one or two ultrasonic units. Domicini et al. (40) suggested that the vibrational energy generated during ultrasonic vibration application is transmitted from the tip to the post and absorbed by the canal walls, potentially creating localized stress concentrations in the dentin that contribute to defect formation. The use of the spring-activated device resulted in the highest number of dentinal defects (n = 35; 33.9%). However, no prior studies have addressed the impact of this technique on root dentin integrity during cast post removal, limiting direct comparison and interpretation of this finding. Further investigations are needed to clarify the biomechanical effects of spring-activated systems on root structure.

A higher number of defects was observed in sections located 12 mm and 8 mm from the apex. The higher incidence of coronally positioned defects may be attributed to the excessive tapering of the root canals, potentially caused by the use of the BR0 (#25/.08) instrument during initial instrumentation (6, 21) and the #4 Largo drill during post space preparation (6, 19). Another possible explanation relates to the application method of the ultrasonic and traction tips. In the present study, both tips were applied adjacent to the cervical region, close to the cementation line, to maximize the transmission of energy to the cast post (6, 10, 11). This approach may have increased stress concentration in the coronal portion of the root canal walls, thereby favoring defect formation in this region. Further studies are necessary to confirm this finding and better understand the stress distribution associated with each post removal technique. This study has limitations. As an ex vivo investigation, the findings may not fully reflect clinical conditions. The results are device- and brand-specific, reflecting only the tips, burs, units, and settings tested, and therefore may not be generalizable to other systems or protocols. Moreover, long-term aging and thermomechanical cycling were not simulated, so time-dependent changes in dentin or cements were not assessed.

While the clinical implications of dentin defects remain a subject of ongoing debate, the present findings underscore the need for cautious selection of post removal strategies. Minimizing iatrogenic damage to dentin is essential for preserving the long-term structural integrity and function of endodontically treated teeth. Future research should aim to refine these techniques and develop safer, more predictable approaches for post removal.

Conclusion

All evaluated techniques for cast post removal - using ultrasonic vibration, carbide burs, and a spring-activated device - resulted in the formation of dentinal defects. The spring-activated method was associated with a significantly greater incidence of root fractures when compared to the other removal protocols. Dentinal defects were more frequently observed in coronal (12 mm) and middle (8 mm) thirds of the root.

Clinical relevance

Crack lines and microcracks formed

during endodontic and restorative procedures may progress into vertical root fractures, which are a major cause of tooth loss in root canal–treated teeth. Therefore, identifying the procedures most likely to induce dentin defects is essential for effective prevention.

Author Contributions

C.N.R.C., C.R.A.E., C.E. and O.A.G. designed the study; C.N.R.C., J.M.S., L.J.P.S.G.M., G.S.C. and D.A.D. contributed to data collection and per-formed statistical analysis; C.N.R.C., C.R.A.E., J.M.S., L.J.P.S.G.M., G.S.C. and D.A.D. drafted the manuscript; C.E., O.A.G. critically revised the article for important intellectual content. All authors approved the final version of the manuscript and agree to be accountable for all aspects of the work.

Conflict of interest

All authors declare that they have no conflicts of interest related to this study.

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ORIGINAL ARTICLE

Endodontic infections in a Portuguese population with self-reported cardiovascular disease - a cross-sectional study

Aim: *To assess the prevalence of apical periodontitis, root-filled teeth, and related covariates, considered potential risk factors for cardiovascular diseases in patients with a self-reported cardiovascular disease history, who first attended the Faculty of Dentistry, University of Porto, in 2018.*

Methodology: *Out of 2,063 reviewed medical and dental records, 1,841 individuals met the inclusion criteria. Endodontic infections and oral status were assessed through orthopantomography. Cardiovascular disease classification was based on self-reported diagnosis. Medical history included dichotomous data on hypertension, diabetes mellitus, and smoking. Bivariate analyses were conducted using Student's t-test for quantitative variables and Pearson's Chi-square test for categorical variables (95% CI, $\alpha = 0.05$). Multivariate logistic regression assessed the impact of confounders on the presence of apical periodontitis and root-filled teeth. Statistical significance was set at $p < 0.05$.*

Results: *The prevalence of apical periodontitis and root-filled teeth was 72% and 57% in patients with cardiovascular diseases, and 45.6% and 47.8% in those without. Bivariate analysis revealed significant associations between cardiovascular disease and age, gender, number of teeth, apical periodontitis, hypertension, diabetes, and smoking. No significant association was found between cardiovascular disease and root-filled teeth. In the multivariate model, the association between apical periodontitis and cardiovascular disease was no longer statistically significant.*

Conclusion: *Although the prevalence of apical periodontitis and root-filled teeth was higher in patients with self-reported cardiovascular disease, no significant association was observed. Hypertension and smoking emerged as key risk factors for cardiovascular disease. Further research is warranted to clarify the potential link between endodontic infections and cardiovascular conditions.*

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Introduction

Apical periodontitis (AP) is an immunoinflammatory reaction of the periradicular tissues to a polymicrobial infection originating in the root canal system, often leading to bone resorption (1). It is a highly prevalent oral condition, affecting nearly half of the adult population (2). The prevalence of AP is higher in individuals with systemic conditions (63%) compared to healthy individuals (48%) (2). Its occurrence has increased over the past decade in both endodontically treated and untreated teeth (3). Diabetes mellitus, cardiovascular diseases (CVDs), and smoking were identified as significant factors influencing AP prevalence (2). Overall, AP affects approximately 5% to 6.3% of all teeth. In root-filled teeth (RFT), the prevalence is higher, around 7.4%, with 39%–41% of individuals presenting at least one RFT showing signs of AP. In contrast, untreated teeth show a lower prevalence, ranging from 3% to 3.5% (2, 3).

Endodontic treatment is commonly performed worldwide, with an estimated 8.2% of all teeth having undergone root canal therapy. Approximately 56% of individuals have at least one RFT, reflecting the widespread use of this treatment (4). The success of endodontic therapy can be influenced by systemic conditions such as diabetes mellitus, smoking, and hypertension (5), which may impair periapical healing (6, 7). Additionally, the overall oral inflammatory load—including the number of carious lesions, residual roots, and remaining teeth—may contribute to a systemic pro-inflammatory state, potentially increasing cardiovascular risk (6).

CVDs are a leading global public health concern, responsible for approximately 19.1 million deaths in 2020 (8). This group of disorders affects the heart and blood vessels, including conditions such as coronary heart disease, stroke, peripheral artery disease, and rheumatic heart disease. CVDs significantly impact quality of life and healthcare systems, with a prevalence of 48.6% among adults, rising with age. In 2020, deaths from heart disease and stroke surpassed those from cancer and chronic respiratory diseases (9). Common risk factors include diabetes mellitus, smoking, and hypertension (10, 11).

Hypertension has long been recognized as a major risk factor for fatal cardiac disorders. Endodontists should be aware of the systemic implications of endodontic procedures and the need for multidisciplinary management, making it essential to stay updated on current guidelines and ensure proper blood pressure control before dental treatment (12).

Recent studies have investigated the potential bidirectional relationship between endodontic infections, and systemic diseases, highlighting the complex interplay between local and systemic inflammatory processes (13). However, the underlying mechanisms remain a subject of debate, largely due to the presence of various confounding factors (14-16). Several findings support a biologically plausible link between endodontic inflammation and cardiovascular outcomes, including the presence of gram-negative anaerobes, local release of pro-inflammatory cytokines, and elevated systemic inflammatory markers and endothelial activation in patients with AP—features also associated with atherosclerosis and acute cardiovascular events (17, 18). Nonetheless, the evidence remains insufficient to establish a conclusive association.

Thus, this cross-sectional study primarily aimed to assess the prevalence of AP and RFT in patients with self-reported CVDs who first attended the Faculty of Dental Medicine of the University of Porto in 2018. A secondary objective was to evaluate other known covariates, including the number of carious lesions, the number of teeth and residual roots present, as well as systemic conditions considered potential risk factors for CVDs. The null hypothesis stated that patients with self-reported CVDs would not exhibit a higher prevalence of AP or

RFT, nor be more affected by their oral inflammatory status, compared to individuals without self-reported CVDs.

Materials and Methods

Patient's selection

The present study analysed data from 2,063 medical and dental records from the Faculty of Dental Medicine of the University of Porto. Data were collected from all patients attending their first-ever appointment for routine dental care at the faculty's pedagogic clinic in 2018. To avoid data duplication, only first-time visits were included. The study was approved by the institution's ethics committee (research project 9/2025) and conducted in accordance with the STROBE guidelines for observational studies (19). Only patient data that met the study's inclusion criteria were used (n=1,841), that is, individuals over 18 years old, with more than eight teeth, complete clinical records, and digital panoramic radiographs. Patients who did not meet these criteria were excluded from the study (n=222). The CVD group of diseases was classified according to the World Health Organization Guidelines Subcommittee's criteria (8). However, the patient data included were based on self-reported diagnoses. Patients who did not self-report any form of CVD and had their first appointment at the Faculty of Dental Medicine of the University of Porto during the same period served as the non-CVD group.

Data collection

Sociodemographic (age and gender) and medical variables were collected. Systemic conditions like hypertension, diabetes mellitus, and smoking habits were recorded from the medical history using a dichotomous response (yes/no). Regarding smoking habits, patients were categorized as non-smokers if they had never smoked and smokers if they were current or former smokers, according to other studies (20). As for hypertension, to apply stricter inclusion criteria, only patients who were taking anti-hypertensive medication were considered (20).

Two qualified endodontists with 20 years of clinical experience (NV and IM) examined panoramic radiographs on a computer screen, blinded to the patient's medical histories. All teeth, except third molars and dental implants, were assessed. For each patient, the following variables were evaluated: the number of RFT, number of teeth with AP, prevalence of teeth with AP in RFT (RFT-AP), prevalence of teeth with AP but without root fillings – designated as untreated teeth with AP (UT-AP), number of teeth present, number of teeth with caries or restorations (designated as caries experience), and number of residual roots. Teeth were classified as RFT if any radiopaque material was visible in the root canals. The prevalence of AP, RFT, RFT-AP, and UT-AP was determined by calculating the percentage of individuals with at least one affected tooth. The oral status was described based on the number of teeth present, caries experience, and number of residual roots, per individual, following the methodology of previous studies (21, 22).

Periapical Status Assessment and Radiographic Evaluations

The condition of the periapical tissues was evaluated using the periapical index of Orstavik (PAI) (23). AP was diagnosed when the scores were greater than two (PAI ≥ 3). For multi-rooted teeth, the highest recorded score was considered the tooth's PAI score. All panoramic radiographs were taken using an Orthoralix® 9200 DDE (Gendex) orthopantomograph and assessed with VixWin Platinum® software, which allows for adjusting the image size and contrast.

Examiner`s Calibration

Previously, the examiners participated in a PAI system calibration course (23), which involved independently evaluating the radiographs twice. Intraobserver reproducibility was assessed by scoring the radiographs of 50 patients, randomly selected, and two months after the initial examination, re-scoring the same radio-

Table 1
Characteristics of the examined variables per individual in the total sample (SD, standard deviation; AP, apical periodontitis; RFT, root-filled teeth; RFT-AP, root-filled teeth with apical periodontitis; UT-AP, untreated teeth with AP).

Table 2
Prevalence and types of cardiovascular diseases (CVDs) (8) self-reported in the study population

Table 3
Prevalence of individuals with self-reported systemic conditions associated with cardiovascular risk factors.

graphs. Cohen's kappa values of 0.70 and 0.72 were calculated. The interobserver calibration for PAI yielded a Cohen's kappa of 0.71. In cases of disagreement a senior professor (IPV) joined the discussion to reach a consensus.

Statistical Analysis

Data were recorded in Microsoft Excel (Microsoft Corporation) and then imported into IBM SPSS Statistics (Version 30.0; IBM Corp.). For descriptive statistics, results were expressed as mean ± standard deviation (SD) for continuous variables and as frequency and percentage for categorical data. Bivariate analyses of quantitative variables between the CVD and non-CVD groups were performed using the student's t-test, while categorical variables were analyzed using Pearson's Chi-square test (CI 95%, $\alpha = 0.05$). The effect of potential confounding factors on the risk of AP and endodontic status (RFT) was assessed using multivariate logistic regression. In accordance with the established significance level, a p-value <0.05 was considered statistically significant.

Results

Data from 1,841 patient records were analysed in this study (Table 1). The average age was 43.8 ± 17.6 years, with women having an average age of 43.0 ± 17.2 years and men 45.1 ± 17.9 years.
The prevalence of individuals with CVDs in the sample was 5.8% (n=107). Table 2 shows the frequencies and types of CVDs identified in the studied population, according to the WHO (8).
Table 3 shows the prevalence of self-reported systemic conditions related to the occurrence of CVDs (risk factors for CVDs).
Table 4 shows the distribution of the examined variables between the CVD and non-CVD groups and analyzes their association with CVDs.
In the CVD group, 72% of individuals had at least one tooth with AP (prevalence of AP), and 57% had at least one RFT (prevalence of RFT). In comparison, the non-CVD group showed prevalence's of 45.6% for AP and 47.8% for RFT. The difference in AP prevalence between the groups was statistically significant, while the difference in RFT prevalence was not. However, significant differences were found between the CVD and non-CVD groups in the prevalence of individuals with at least one RFT with AP (RFT-AP), as well as those with at least one untreated tooth with AP (UT-AP). To examine variables related to oral status (number of teeth present, caries experi-

Variables	Total
Age (years), mean ± sd	43.8 ± 17.6
Gender, n (%) - Male	761 (41.3)
Gender, n (%) - Female	1080 (58.7)
Number of teeth with AP, mean ± sd	0.9 ± 1.3
Prevalence of AP, n (%)	867 (47.1)
Number of RFT, mean ± sd	1.2 ± 2.0
Prevalence of RFT, n (%)	889 (48.3)
Prevalence of RFT-AP, n (%)	494 (26.8)
Prevalence of UT-AP, n (%)	561 (30.5)
Number of teeth present, mean ± sd	23.8 ± 5.1
Caries experience, mean ± sd	5.4 ± 4.6
Number of residual roots, mean ± sd	0.4 ± 2.0

Table 1

Cardiovascular Diseases	Frequency, n (%)
Stroke	61 (57.0)
Myocardial infarction	18 (16.8)
Cardiac arrhythmia	15 (14.0)
Heart failure	6 (5.6)
Aneurysm	3 (2.8)
Others	4 (3.8)

Table 2

CVDs-systemic related conditions	Frequency, n (%)
Hypertension, n (%)	377 (20.5)
Diabetes mellitus, n (%)	123 (6.7)
Smoking Habits, n (%)	698 (37.9)

Table 3

Variable	CVD group (n=107)	Non-CVD group (n=1734)	p value
Age (years), mean ± SD	60.9 ± 13.7	42.8 ± 17.2	<0.001*
Gender, n (%)			0.010*
Male	57 (53.3)	704 (40.6)	
Female	50 (46.7)	1030 (59.4)	
Number of teeth with AP, mean ± SD	1.8 ± 1.6	0.9 ± 1.3	<0.001*
Prevalence of AP, n (%)	77 (72.0)	790 (45.6)	<0.001*
Number of RFT, mean ± SD	1.3 ± 1.8	1.2 ± 1.8	0.161
Prevalence of RFT, n (%)	61 (57.0)	828 (47.8)	0.063
Prevalence of RFT-AP, n (%)	39 (36.4)	455 (26.2)	0.021*
Prevalence of UT-AP, n (%)	60 (56.1)	501 (28.9)	<0.001*
Number of teeth, mean ± SD	19.4 ± 6.1	24.1 ± 4.9	<0.001*
Caries experience, mean ± SD	5.7 ± 4.9	5.4 ± 4.5	0.242
Number of residual roots, mean ± SD	0.6 ± 1.2	0.4 ± 2.1	0.236
Hypertension, n (%)	67 (62.6)	310 (17.9)	<0.001*
Diabetes, n (%)	20 (18.7)	103 (5.9)	<0.001*
Smoking Habits, n (%)	57 (53.3)	103 (37.0)	<0.001*
statistical significance (p<0.05)			

Table 4
Distribution of the examined variables in the CVD and non-CVD groups. (SD, standard deviation; AP, apical periodontitis; RFT, root-filled teeth; RFT-AP, root-filled teeth with AP; UT-AP, untreated teeth with AP).

ence, and number of residual roots), a Student's t-test was conducted to evaluate differences in the mean values between the CVD and non-CVD groups. Significant differences were found in the mean number of teeth present between the two groups. Regarding variables representing risk factors for CVDs, such as hypertension, diabetes, and smoking habits, significant differences were also observed between the CVD and non-CVD groups.
To identify the factors associated with periapical status (AP prevalence), a multivariate logistic regression analysis was performed using a forward stepwise method.
The dependent variable was "periapical status" (0 = no teeth with AP; 1 = at least one tooth with AP). Age, gender, number of teeth, caries experience, number of residual roots, presence of at least one RFT, presence of CVD, hypertension, diabetes mellitus, and smoking habits were the independent variables included in the analysis. In the final model, a statistically significant positive correlation is shown in Table 5. The number of teeth present showed a statistically significant negative correlation with AP, with a higher number of teeth being associated with a reduced likelihood of having AP.
Finally, a multivariate logistic regression was performed to assess the factors associated with the dependent variable "endodontic status" (0 = no RFT; 1 = at least one RFT). The independent variables included in the model were: age, gender, number of teeth, caries experience, number of residual roots, presence of AP, presence of CVD, hypertension, diabetes mellitus, and smoking habits. Age (OR = 1.0; 95% CI = 1.012–1.025; p<0.001), female gender (OR = 0.7; 95% CI = 0.578–0.916; p = 0.007), prevalence of AP (OR = 3.1; 95% CI = 2.472–3.961; p < 0.001) and caries experience (OR = 1.3; 95% CI = 1.283–1.371; p < 0.001) were found to be significantly associated with the presence of RFT.

Discussion

The hypothesis that AP may be associated with systemic conditions, particularly CVDs, is supported by cross-sectional and longitudinal studies as well as biologically plausible mechanisms.

					95% C.I. for OR	
Independent variables	B	SE	p value	OR	LL	UL
Age (years)	0.013	0.005	0.005*	1.014	1.004	1.023
Gender	0.115	0.015	0.338	1.121	0.887	1.418
Caries experience	0.101	0.064	<.001*	1.106	1.075	1.139
No. of residual roots	0.229	0.015	<.001*	1.257	1.109	1.424
No. of teeth	-0.074	0.118	<.001*	0.928	0.902	0.955
Smoking Habits	0.895	0.181	<.001*	2.447	1.941	3.087
Diabetes	0.208	0.149	0.392	1.231	0.765	1.981
Hypertension	0.488	0.127	0.007*	1.629	1.144	2.321
CVD	0.124	0.504	0.629	1.132	0.684	1.873
No. of RFT	1.155	0.005	<.001*	3.174	2.474	4.072
Constant	-0.767	0.015	0.128	0.465		
*statistical significance (p<0.05)						

Table 5
Multivariate logistic regression analysis of factors associated with AP using forward stepwise selection (B, logistic regression estimated coefficient; S.E., estimated standard error for the estimated coefficient; p value, value associated with the statistical coefficient test; OR, estimated odds ratio; CI, confidence interval of 95% for odds ratio; LL, lower limit; UL, upper limit).

This cross-sectional study aimed to assess the prevalence of AP and RFT in a Portuguese population attending their first appointment at the Faculty of Dentistry, University of Porto, in 2018, and to explore their association with self-reported CVDs. The recruitment followed a methodology similar to that used in previous studies in Portugal (24-26) and internationally (21, 22). The inclusion of 1,841 patients provide a relatively large sample size, which strengthens the reliability and consistency of the observed associations. As in related studies (20, 22,26-28), we excluded patients with fewer than eight teeth, a criterion likely to reduce the risk of diagnostic confounding between endodontic and periodontal conditions.

The overall prevalence of AP in our study was 47.1%, per individual, consistent with recent systematic reviews and meta-analyses (2, 3). Compared to the previously reported prevalence of 44.2% in a Portuguese population in 2014 (25), our findings suggest a stable but slightly increasing trend. This pattern is in line with the findings of Razdan, Jungnickel (29), who observed a rise in the relative frequency of AP in a Danish population over a 10-year period (1997–2007). While a declining trend in RFT was observed in the Danish population (29), our study found a 48.3% prevalence of RFT (compared to 47.2% in 2014), suggesting that the prevalence of both AP and RFT in Portuguese samples has remained relatively stable over the past decade (25). A 2012 Portuguese study reported lower rates of AP and endodontic treatment, possibly reflecting a less conservative endodontic approach, where increased extractions may have reduced the observed prevalence of AP (26).

A cone-beam computed tomography (CBCT) study conducted in a Scottish sub-population, using data collected from 2009 to 2012 (30), reported AP in 5.8% of 3,595 teeth assessed from dentate patients over 18 years of age. With a similar methodology, a study in Portugal analyzing scans from eight private health centers (2012–2018) found an overall AP prevalence of 10.4% per tooth (31). While highlighting the superior diagnostic accuracy of CBCT compared to conventional radiographs, the authors noted that this prevalence still falls within the range (1.4%–15.1%) reported in earlier studies using either panoramic radiographs (32, 33) or CBCT (30, 34). In line with these findings, a previous Portuguese study using panoramic radiographs (26) reported an AP prevalence of 1.7% (PAI ≥ 3) across 5,552 teeth. More recently, systematic reviews and meta-analyses based on panoramic radiographs estimated global AP prevalence at 6.3% (3) and 5.0% (2) per tooth.

A significant association was observed in the bivariate analysis between CVDs and both the number of teeth with AP and the prevalence of AP, defined as the presence of at least one affected tooth per individual. In contrast, no significant association was found between CVDs and either the number or prevalence of RFTs. However, after adjusting for potential confounders in the multivariate model, the association between AP and CVDs lost statistical significance. These findings contrast with those reported by Caplan, Pankow (35), who, in a prospective study, found that individuals with a higher self-reported history of endodontic treatment and with 25 or more teeth were more likely to have coronary heart disease. Similarly, the Baltimore Longitudinal Study (36) identified endodontic burden—defined as the combined presence of AP and RFT—as an independent mid-life predictor of cardiovascular events. Nonetheless, both studies highlight the need for prospective research to better understand the epidemiology of endodontic infection and to assess whether treating AP might reduce cardiovascular risk. It is important to note that differences in methodology may influence the variables assessed and partially explain these inconsistencies.

Similarly, in a pair-matched cross-sectional study An, Morse (21) using medical and dental chart review (full-mouth radiographs) from hospital records, a bivariate association between AP and CVDs was reported. Supporting these findings, González-Navarro, Segura-Egea (22) also identified a significant association between AP and atherothrombotic cardiovascular events in a matched study using clinical exams and panoramic radiographs. Corroborating the present study, RFT were not significantly associated.

Unlike the aforementioned studies (21, 22), which used electronic medical records and ICD-9-CM codes to confirm CVD diagnoses, our study relied on self-reported health data. Although common in epidemiological research, self-reported information has known limitations, particularly in the accuracy of medical and dental history, as individuals may be unaware of past or existing conditions, leading to possible misclassification. Nevertheless, this method remains an accepted approach for assessing both AP, RTF and CVD status (2, 35, 37). Age differed between the CVD and non-CVD groups and is associated with AP, RFT, CVD, and related risk factors, representing a potential confounder. Although this is a study limitation, not matching for age (and gender) allowed us to explore their possible influence as effect modifiers. As in most epidemiological studies assessing the prevalence of AP (3), we relied on panoramic radiographs for diagnosis. Although CBCT offers greater sensitivity (38), it is not yet considered the standard imaging modality for population-based research. The most recent position statement from the European Society of Endodontology (ESE) recommends CBCT only for specific clinical indications (39). Therefore, conventional radiography remains the primary diagnostic tool in epidemiological contexts, even though it may underestimate the true prevalence of AP (38). To address the limitation of not conducting clinical examinations, periapical status and the prevalence of RFT were assessed using panoramic radiographs. This method considered appropriate for epidemiological research (2), may help explain, along with other methodological differences, the discrepancies observed across studies. Despite a moderate Cohen's kappa value (40), the reliability of the radiographic assessment—conducted by two senior dentists specialized in Endodontics and blinded to participants' systemic and oral health status—was reinforced by the involvement of a third senior endodontist, who resolved any discrepancies by consensus.

A secondary objective of this study was to investigate additional oral and systemic factors associated with CVD risk. Significant associations were observed between CVDs and variables such as age, number of teeth with AP, number of untreated AP lesions, and total number of teeth, indicating a poorer oral health among individuals with CVDs. The complexity of the oral microbiome still poses significant challenges, particularly regarding the role of microorganisms and their metabolites in oral infections and subsequent tissue inflammation (41). Elevated levels of pathogenic bacteria in dental plaque trigger an exaggerated immune response. Bacterial components, such as lipopolysaccharides (LPS), stimulate the production of inflammatory mediators and cytokines, which in turn activate matrix metalloproteinases (MMPs) responsible for degrading the extracellular matrix and promoting bone resorption. These pathological processes extend beyond the oral cavity, impacting systemic health. Endothelial dysfunction, an early marker and independent predictor of cardiovascular events, underscores the need for a broader understanding of these mechanisms to enable prevention and reduce the healthcare burden (42).

These findings are consistent with previous studies (21), which reported associations between CVDs and indicators of compromised oral health, including missing teeth, caries, and the number of RFTs. Supporting this evidence, Cotti and Mercuro (43) linked endodontic infections and poor oral health to early vascular changes and increased CVD risk. Similarly, González-Navarro, Segura-Egea (22) emphasized the role of cumulative oral inflammatory burden, including caries, periodontal disease, AP, and furcation lesions, in relation to CVDs, distinguishing it from metabolic syndrome (MetS), a systemic condition marked by hypertension, hyperglycemia, and abdominal obesity, which also contributes significantly to cardiovascular risk.

Several factors have been identified as influencing AP prevalence: country income level (with higher rates in developing countries), setting of recruitment (with higher rates in dental care services), presence of systemic conditions, study quality and risk of bias, radiographic method (e.g., higher prevalence in CBCT-based studies), and diagnostic criteria (e.g., lower prevalence when using stricter PAI thresholds). These findings underscore the need for greater awareness among health policymakers and professionals regarding the often-overlooked burden of endodontic disease at the population level (2). Although previous studies have suggested a potential link between chronic endodontic infections and CVD, the overall quality of evidence remains limited (10). Globally, diabetes mellitus, smoking, and hypertension are recognized as major CVD risk factors (44). Diabetes mellitus is a widespread condition and was among the first systemic diseases investigated for associations with endodontic infection. While many studies have shown that AP can both worsen and be exacerbated by diabetes mellitus, results remain inconsistent (45). In our bivariate analysis, hypertension and smoking were significantly associated with both CVDs and AP ($p < 0.05$), whereas diabetes was significantly associated with CVDs, but not a predictor for AP.

Comorbidities like smoking and hypertension were also more prevalent in the CVD group. Smoking has been linked to a pro-inflammatory state, impaired immune function, and delayed healing, which may contribute to the development of AP. Previous studies have reported an association between smoking and increased AP incidence (46, 47), likely due to enhanced bone resorption and reduced pulp defense. However, the literature remains inconclusive. An, Morse (21) found no association between smoking and AP, although they did report links with hypertension, caries, missing teeth, and RFTs. Similarly, González-Navarro, Segura-Egea (22) observed no significant differences in smoking or diabetes status between CVD and control groups. In contrast, Portuguese studies have shown a positive association between smoking and AP. Correia-Sousa, Madureira (24) reported a general link, while Melo, Ferreira (25) identified a significant association with multiple AP lesions (≥3; $p = 0.025$). However, neither Melo´s study nor the present one found a significant association between smoking and RFT prevalence, diverging from earlier findings by Correia-Sousa's (24). Supporting the broader role of smoking in endodontic outcomes, Krall, Abreu Sosa (48) reported that current smokers were 1.7 times more likely to undergo root canal treatment than never-smokers. A later study (20) reported AP in 92% of hypertensive patients who also smoked. Together, these findings reinforce the potential impact of hypertension and smoking on periapical health and support the associations observed in our study.

A key finding of the current Portuguese investigation was the strong association between CVDs and hypertension, a well-established major risk factor for atherosclerosis and related conditions (49). Hypertension was defined according to the criteria established by Caplan, Pankow (35) and Segura-Egea, Castellanos-Cosano (20) using self-reported antihypertensive medication use to improve diagnostic reliability. Other studies have similarly used thresholds of systolic blood pressure ≥130 mmHg, diastolic ≥85 mmHg, or current treatment to define hypertension (22). An association between hypertension and AP was also observed, aligning with previous findings (21, 22). Although severe cardiovascular conditions may not have been prevalent in this sample, the notable proportion of hypertensive individuals under medication (20.5%) underscores the importance of early detection and management. Given hypertension's modifiable nature, proactive intervention remains critical in reducing the burden of CVDs (49).

Hypertensive individuals had 1.629 times higher odds of presenting with AP ($p < .005$), while smokers had 2.447 times higher odds ($p < .001$). Importantly, our findings should not be interpreted as evidence of causality. As emphasized by Jiménez-Sánchez, Cabanillas-Balsera (50) the association does not imply causality. Shared risk factors between CVDs and endodontic disease may act as confounders, introducing bias into the observed associations. Inconsistencies across studies may be explained by variations in methodology, participant characteristics, sample sizes, diagnostic criteria for AP and CVDs, and statistical approaches. Additionally, unmeasured confounding variables, such as socioeconomic status, access to healthcare, and oral health behaviors, may have influenced the results in different ways (2). Longitudinal studies with standardized methodology, although crucial for assessing temporality and dose–response relationships, face practical challenges such as dropout rates and methodological variability. Thus, despite the inherent limitations of cross-sectional studies, they remain valuable for identifying potential risk indicators in diverse populations, thereby informing and guiding future longitudinal research.

Conclusions

Our findings confirm the high prevalence of endodontic infections, with nearly half of the assessed individuals presenting at least one tooth with AP and one RFT. This supports the general trend of a stable or slightly increasing prevalence over the past decade. However, no strong evidence was found linking AP or RFT to CVDs. Individuals with CVDs also showed poorer overall oral health. The broad definition of CVD and the reliance on self-reported medical data were among the limitations of the present study. However, the large sample size and the strict criteria for hypertension underscored the significance of this often silent condition. Notably, AP was significantly associated with smoking and hypertension, both well-established risk factors for atherosclerosis and cardiovascular events. Given the rising burden of CVDs, hypertension, smoking, and AP, further longitudinal and interventional studies are warranted to clarify potential causal relationships and guide preventive strategies.

Conflict of interest

None.

Acknowledgments

None.

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REVIEW ARTICLES

How Does a Calcium Phosphate-Based Biomimetic Ceramic Function as a Direct Pulp-Capping Agent? A review

ABSTRACT

Alternative calcium phosphate-based (CaP) bioceramics are currently being developed for direct pulp capping (DPC). These substances have the potential to minimize the adverse effects of certain cements while promoting reparative and regenerative processes.

Aim: *To compile available evidence of the biological processes triggered in the dentin-pulp complex when DPC is performed with CaP-based materials.*

Methodology: *A literature search was conducted between 2014-2024 in 20 databases published using "pulp capping" and "calcium phosphates". Articles involving bioceramics combined with metals, non-metals (e.g., fluorides), or polymers were excluded.*

Results: *Eighteen articles were selected. Information was classified into three categories: a)Pulp repair, b)ionic activity and their role in dentin growth regulation, and c)the environment. It was evidenced that CaP materials stimulate the proliferation and differentiation of pulp stem cells and fibroblasts into odontoblast-like cells, as demonstrated by the expression of ALP, OCN, DSPP, and DMP-1. These cells express nestin and promote the development of mineralized nodules, leading to the formation of a dentinal bridge. Essential ions, including calcium, phosphorus, hydroxyl, and magnesium, play key roles in regulating cell proliferation and differentiation processes. They maintain a pH of 7.0-8.2, leading to better integration with surrounding tissues, while also enhancing biomineralization and apatite formation.*

Conclusion: *CaP-based materials have been shown to stimulate the proliferation and differentiation of pulp stem cells into odontoblast-like cells, which are primarily responsible for pulp repair and regeneration. These materials also stimulate the creation of a favorable environment by supplying essential ions to regulate pH, modulate protein expressions, and promote dentin mineralization.*

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Introduction

In contemporary dentistry, maintaining pulpal vitality in teeth has become a central therapeutic objective. The preferred treatments are indirect pulp capping (IPC) and direct pulp capping (DPC), both representing alternative techniques to root canal treatment for preserving pulp vitality when exposure occurs due to deep caries, mechanical instrumentation, or dental trauma (1) Indirect pulp capping involves the removal of most of the decayed dentin, followed by the subsequent placement of a bioceramic material to facilitate tooth restoration. In contrast, DPC involves placing a bioceramic material directly on the exposed pulp after caries removal to stimulate mineralization and tissue repair (2).

Bioceramics are inorganic, biocompatible, bioactive, conductive, non-corrosive, and chemically stable materials. They exert biological effects on cells and pulp tissue, supporting the control of inflammation, remineralization, and dentin repair. They also contribute to isolating the exposed tissue from the external environment. There are currently different bioceramic materials for direct pulp capping. These include calcium hydroxide-based formulations (CH)-which are increasingly falling out of use-; tri- and dicalcium silicate-based materials (MTA ProRoot*, MTA Angelus*, Biodentine*); and calcium phosphate-based materials (CaP) (3-6).

Although tri- and dicalcium silicate-based bioceramics (MTA or Biodentine) have shown improvements in their physical, chemical, and biological properties, their primary mechanism of action relies on dentin-bridge formation in proximity to the pulp. The formation of a hydroxyapatite-like layer along the bottom of the cavity and the maintenance of pulp vitality are achieved in more than 80% of the cases of DPC. However, these materials do not enable the replacement of the bulk of the tooth, the re-establishment of an ortho-dentin tubular microstructure, or the formation of an odontoblastic layer serving as a barrier. (7)

Calcium-phosphate-based (CaP) materials have been recently introduced for DPC. Their mechanism of action and effectiveness rely on facilitating pulp cell migration, inducing odontoblastic differentiation (8), and forming restorative dentin on the affected surface by releasing Ca^{+2} and OH^{-1} ions (4,8—12). The release of Ca^{+2} appears to play a critical role in the transduction and signaling of biological processes, as well as in the formation of mineralized matrices (1, 13-15). This explains why a new CaP QCP bioceramic derived from eggshell, has been developed (16). This novel QCP exists in different versions; version 5 consists of tricalcium phosphate (TCP), sintered hydroxyapatite (HAp), and amorphous HAp combined with other compounds or chemical elements such as carbonates, potassium, sodium, chlorine, and magnesium, without silicates or toxic anions or cations (3). Nevertheless, further studies are required to elucidate how this material interacts with the biological and cellular processes occurring within the dentin-pulp complex.

The primary aim of this review is to synthesize available data and construct a comprehensive map of the biological processes occurring in the dentin-pulp complex during direct pulp capping using calcium-phosphate (CaP)-based materials. This objective is addressed by analyzing research findings and information reported in the literature. Such an approach may contribute to the development of a theoretical model framework that enhances understanding of these biological processes and supports future research on the use of CaP-based materials in direct pulp capping procedures. Ultimately, this may help identify the most suitable types of CaP materials for direct dental pulp capping procedures.

Materials and methods

Literature search

A preliminary search was conducted for articles addressing direct pulp capping published in English and Spanish between 2014 and 2024. Due to the limited number of eligible studies, the search range was subsequently broadened to maximize the retrieval of relevant evidence and minimize selection bias.

The following databases were queried: PubMed, Embase, Cochrane Library, Web of Science, Wiley Online Library, Scopus, ScienceDirect, SciELO, LILACS, Google Scholar, ERIC, SpringerLink, Academia.edu, BASE, Dialnet, Science Research, Redalyc, RefSeek, Ciencias.Science, and WorldWideScience.

The search strategy included the following keywords: *"pulp capping"* and *"calcium phosphates"*. Articles were excluded if they mentioned different materials or bioceramics combined with metals, non-metals (e.g., fluorides), or polymers, as well as studies conducted on deciduous teeth or those using bioceramics in pulpotomy procedures.

Literature Selection

Two reviewers independently screened the working papers in three stages: title, abstract, and full-text assessment. Articles retrieved through snowball sampling were also considered, and duplicate texts or those not addressing the review question were excluded. Eligibility criteria were determined based on whether the studies addressed the research question.

Information Storage

All data were managed using Mendeley and organized in Excel spreadsheets, classified according to the database from which each article was retrieved.

Results

The search yielded a total of 18 articles, as detailed in Table 1. These comprised two systematic reviews, one in-vivo

Table 1
Flow diagram of the selected articles.

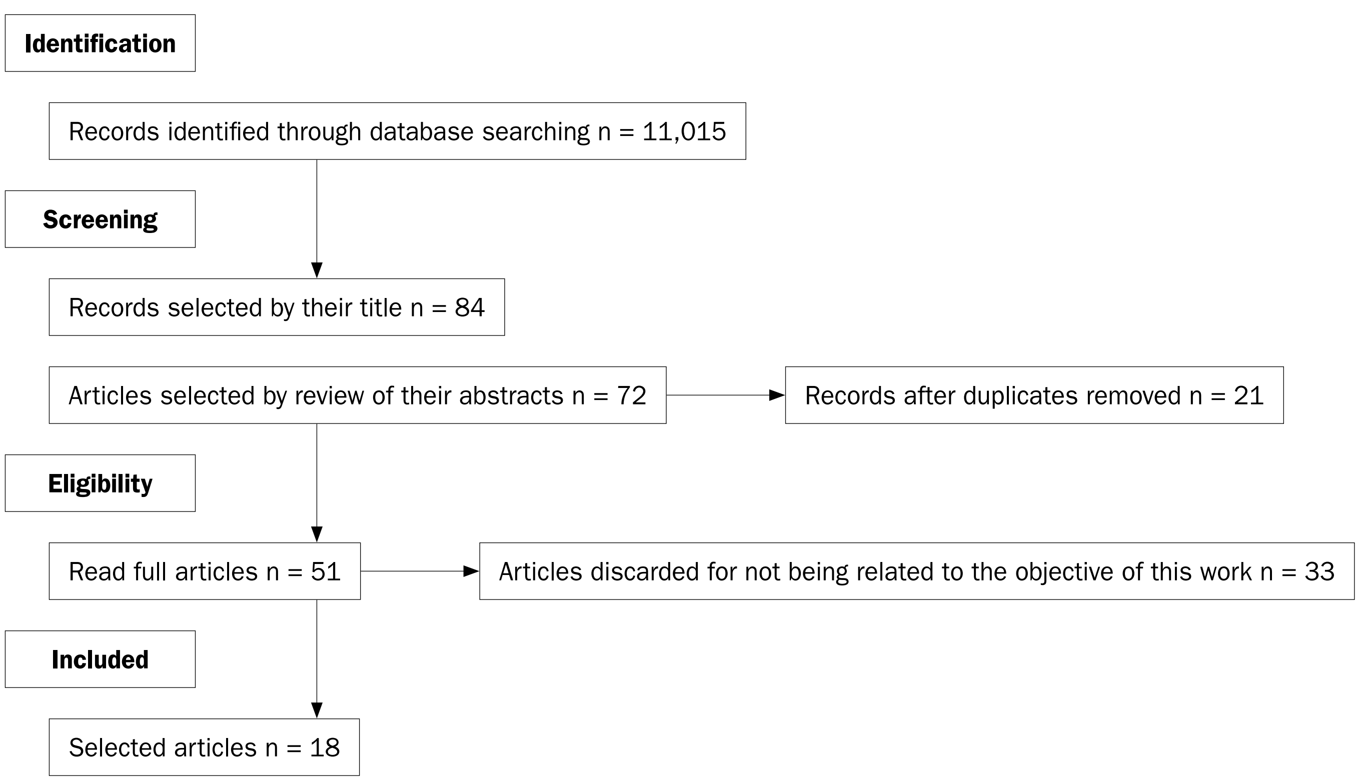

Table 2
Assessment of the reviewed articles

No	YEAR	AUTHOR	ARTICLE'S/SOURCE'S TITLE IN THIS JOB	USE IN THIS REVIEW
SYSTEMATIC REVIEW				
1	2021	Davaie S, Hooshmand T, Ansarifarda S	Different types of bioceramics as dental pulp capping materials: A systematic review (6)	Results
2	2021	C. CălinaM, Sajinb M, T Moldovanc, C.Comand, SI. Stratule, A.C.Didilescua	Immunohistochemical expression of non-collagenous extracellular matrix molecules involved in tertiary dentinogenesis following direct pulp capping: a systematic review (29)	Results
IN-VIVO STUDY				
3	2021	Guerrero-Gironés J, Alcaina-Lorente A, Ortiz-Ruiz C, et al	Biocompatibility of a ha/β-tcp/c scaffolds a pulp-capping agent for vital pulp treatment: An in vivo study in rat molars (22)	Results
IN-VITRO STUDY				
4	2021	Gu Y, Xie X, Zhuang R, Weir MD, Oates TW, Bai Y	A Biphasic Calcium Phosphate Cement Enhances Dentin Regeneration by Dental Pulp Stem Cells and Promotes Macrophages M2 Phenotype In Vitro (23)	Results
5	2020	Javid B, Panahandeh N, Torabzadeh H, Nazarian H, Parhizkar A, Asgary S	Bioactivity of endodontic biomaterials on dental pulp stem cells through dentin (10)	Results
6	2019	Koutroulis A, Kuehne S A, Cooper PR and Camilleri J	The role of calcium ion release on biocompatibility and antimicrobial properties of hydraulic cement (27)	Results
7	2019	Al-Saudi KW, Nabih SM, Farghaly AM, AboHager EA	Pulpal repair after direct pulp capping with new bioceramic materials: A comparative histological study (28)	Results
8	2019	Mahendran K, Ponnusamy C, Maloor SA	Histological evaluation of pulpal response to direct pulp capping using statins with α-tricalcium phosphate and mineral trioxide aggregate in human teeth (19)	Results
9	2018	Salah M, Kataia M M, Kataia E M, Alaa E, Din E, Essad M E	Evaluation of eggshell powder as an experimental direct pulp capping material (30)	Results
10	2015	Li S, Hu J, Zhang G, Qi W, Zhang P, Li P, Zeng Y, Zhao W, Tan Y	Extracellular Ca2+ Promotes Odontoblastic Differentiation of Dental Pulp Stem Cells via BMP2-Mediated Smad1/5/8 and Erk1/2 Pathways (24)	Results
11	2015	Gandolfi MG, Spagnuolo G, Siboni F, Procino A, Rivieccio V, Pelliccioni G A, C. Prat C, Rengo S	Calcium silicate/calcium phosphate biphasic cement for vital pulp therapy: chemical-physical properties and human pulp cells response (26)	Results
12	2014	González-Pita LC, Vargas-Sánchez PK , Delgado-Mejía E, Fittipaldi Bombonato –Prado K, Torres- Rodríguez C.	Response of undifferentiated pulp cells (OD-21) when using biomimetic ceramics for pulp coating (3)	Results
13	2014	Lee Ju- Lee JB, Park, SJ, Kim HH, Kwon, YS Lee, Kwang et al	Physical properties and biological/odontogenic effects of an experimentally developed fast-setting α-tricalcium phosphate-based pulp capping material (17)	Results
LITERATURE REVIEW				
14	2022	Siddiqui Z. Acevedo-Jake A M, Griffith A, Kadincesme N, Dabek K, Hindi D, Kim K K; Kobayashi Y, Shimizu E, Kumar V.	Cells and material-based strategies for regenerative endodontics (20)	Results
15	2021	Fiume E, Magnaterra G, Rahdar A, Verné E, and Baino F.	Hydroxyapatite for biomedical applications: A short overview. (18)	Results
16	2018	Shaofeng An	The emerging role of extracellular Ca2+ in osteo/odontogenic differentiation and the involvement of intracellular Ca 2+signaling: From osteoblastic cells to dental pulp cells and odontoblasts (25)	Results
17	2018	Chaughule, Ramesh S.	Physical Properties and Biocompatibility of Nanostructural Biomaterials Based on Active Calcium Silicate Systems and Hydroxyapatite. (21)	Results
18	2016	Karthikeson PS, Jayalakshmi S.	Pulp capping agents-A review (14)	Results

study, ten *in-vitro* studies, and five literature reviews (Table 2).

Calcium phosphates (CaP) are the main mineral component of teeth. Examples of CaP-based materials used for direct pulp capping (DPC) include hydroxyapatite (HA), Polyphasic calcium phosphates (Poly-CaP), and Tricalcium phosphate (TCP) (12, 14, 17, 18). Tricalcium phosphate (TCP) occurs in two primary forms: α-TCP and β-TCP. The α-form is more soluble and biodegradable, making it suitable for applications such as bone scaffolding and drug delivery. It is also a component of certain cements, where it forms carbonate apatite when mixed with calcium carbonate and monocalcium phosphate monohydrate. (19)

Pulp repair

The pulp–dentin complex has regenerative potential that induces the formation of tertiary dentin. The dentin matrix is not merely a scaffold for the development of mineralized tissue but also serves as a reservoir of growth factors. Dentinogenesis requires materials that stimulate the release of bioactive molecules to signal repair (20, 21).

In this process, stem cells and pulp fibroblasts proliferate and differentiate into odontoblast-like cells, as evidenced by the expression of specific markers, including ALP, OCN, DSPP, and DMP-1. These odontoblast-like cells produce tertiary dentin (17), express nestin, and promote the formation of mineralized nodules by the induction of ALP activity, which has been shown to be critical in the mineralization process (15, 22, 23).

Thus, CaP-based materials do not induce necrotic layer formation; instead, they promote dentin bridge formation, thereby creating a protective barrier that seals the pulp.

The dental pulp also has intrinsic defense mechanisms against external attacks. For instance, odontoblasts and pulp fibroblasts produce pattern recognition receptors (PRRs) capable of detecting bacteria through surface molecules. Activation of the nuclear factor kappa B (NF-KB) pathway subsequently induces the production of inflammatory cytokines and complement C5 pathway, which contributes to the regulation of inflammation (20). In addition, materials such as CaP release ions, which in turn create an environment conducive to this response (15).

Ions and their role in dentin growth regulation

Calcium has been demonstrated to play a pivotal role in various aspects of cellular function, including proliferation, differentiation, and mineralization. It has been observed to enhance the expression of bone morphogenic protein (BMP-2), which has been identified as a key driver of pulp stem cell differentiation. Furthermore, calcium has been shown to regulate the expression of Runx2, a protein that is involved in the formation of mineralization nodules. (6, 17, 22, 24, 25).

Additionally, calcium contributes to the maintenance of pyrophosphatase activity, thereby contributing to the preservation of mineralization and dentin bridge formation (26). Moreover, calcium reacts with carbon dioxide, inhibiting the respiration of anaerobic bacteria (25).

Phosphorus plays a crucial role in the odontogenic differentiation of human dental pulp stem cells (hDPSCs), promoting the expression of odontogenic markers such as RUNX2, OCN, DSPP, and DMP1, all of which are essential for dentin formation. Phosphorus is also a fundamental element in biomineralization, the process by which mineralized tissues, such as dentin, are formed. In this context, this element interacts with calcium to form hydroxyapatite, the main mineral component of dentin.

Hydroxyl ions derived from CaP are released in relatively smaller quantities. This reduced release limits their ability to induce necrotic layer formation and decreases their bactericidal capacity. Furthermore, it is anticipated that the lower release of hydroxyl ions does not provide the same protective barrier as observed in reactions with higher concentrations of these ions. (27).

Calcium and hydroxyl ions, components of the experimental material, stimulate alkaline phosphatase (ALP), while their pH enhances the expression of bone morphogenic protein-2 (BMP-2) (6,15). ALP is an enzyme produced during the early stages of odontoblast maturation (28). At the same time, it is a crucial marker for evaluating pulp coating materials, as it indicates the activity of odontoblast-like cells. Its expression may indicate the onset of cellular differentiation and, in turn, the start of tissue mineralization (10). In comparative studies, this experimental material (QCP5) showed ALP expression levels similar to those observed with MTA (3).

Furthermore, fibronectin also appears to be stimulated by hydroxyl and calcium ions. It acts as a reservoir of growth factors and signaling cues that promote odontoblast differentiation, adhesion, and proliferation (29).

Another cation presented in the experimental material, magnesium (Mg), is essential for enzymatic and cellular reactions, including the bone mineralization process. Several studies indicate that incorporating Mg into apatite crystals can improve odontoblast adhesion to apatite and, therefore, support bone formation (30).

Environment

The environment surrounding odontogenic mesenchymal stem cells (MSCs) is crucial in determining the outcome or prognosis of the pulp regeneration process. The natural pulp environment has been shown to regulate the homeostasis, proliferation, and differentiation of odontogenic MSCs.

Among the factors involved, pH plays a decisive role. An optimal pH range of 7.0 to 7.6 has been shown to favor cellular response (20), enhance odontoblastic cell activity, and increase ALP expression (10), thereby promoting calcification nodules (6, 10, 23) and apatite formation (28).

In one study, CaSi-αTCP silicate exhibited a high level of calcium ion release in its leachate, maintaining high pH levels (pH 8), in contrast to CaSi-DCDP, which showed a lower pH and reduced calcium ion release (26). Another study reported that αTCP maintained alkaline pH values consistently above 7.0 for 14 days without exceeding 8.2. This study also indicated that the alkaline environment created by the material is necessary for reparative dentin formation, as alkalinity appears to induce mild stimulation of cell differentiation (17).

Considering the experimental base material (QCP) in comparison with other similar materials, it can be expected that the pH generated when used as a pulp capping agent is less alkaline than that of calcium hydroxide (12-14), as it induces less inflammation, as demonstrated in in vitro studies (30,31).

Discussion

This review developed a map based on the available literature of the biological processes involved in calcium phosphate (CaP)-based direct pulp capping within the dentin-pulp complex. The information was classified into three main categories.

Calcium phosphate (CaP) is the common name for a family of minerals composed of calcium cations (Ca^{2+}) together with orthophosphate (PO_4^{3-}), metaphosphate (PO3−), or pyrophosphate (P2O74 −) anions, and, in some cases, hydrogen (H+) or hydroxide (OH−) ions (32).

It has been well established that calcium phosphates (CaPs) are characterized by different Ca/P molar ratios, ranging from 0.5 for brushite to 1.67 for hydroxyapatite and even up to 2.0 for tetracalcium phosphate. The Ca/P molar ratio drives the biological performance of the specific CaP being used. For instance, CaP ceramics with a Ca/P molar ratio of 1.59 (HAp: 53%, α-TCP: 21%, β-TCP: 26%) have been reported to significantly enhance cell proliferation and the expression of extracellular matrix genes. Thus, the chemistry of CaP is of utmost importance and should be carefully considered, given that different CaP phases are defined by diverse Ca/P molar ratios, which in turn result in varying calcium (Ca^{2+}) to phosphate ($P0_4^{3-}$) ion release ratios, which directly influence their in vitro performance.
Furthermore, the calcium-to-phosphorus (Ca-P) ion release ratio in the surrounding environment determines whether the used CaP will exhibit osteoinductive or osteoconductive properties (33), as well as its mineralization potential. When this ratio approaches 1.67, the compound is more stable in the body and less soluble (18). The working experimental material is expected to maintain such stability as it contains non-stoichiometric hydroxyapatites (Has) that prevent deviations from the ideal Ca/P value (31).
Conversely, very low Ca/P ratios, such as that of MCPM, entail a narrow pH stability range (0-2.0), accompanied by high solubility (ca. 17 g/L at 25°C), making it unsuitable for biological purposes. As the ratio increases to 1.0, as in brushite, the equilibrium pH ranges from 2.0 to 6.0, and its solubility decreases dramatically to 0.088 g/L at 25°C.

Biodegradation of implanted CaPs may occur through mechanical degradation in biological fluids, physicochemical processes, or biological cell activity. These mechanisms can alter chemical composition, as in the case of TCP (ratio = 1,5), which exhibits incongruent dissolution. This means that the concentration of Ca and orthophosphates does not accurately reflect the composition of solid TCP, leading to the redeposition of a limited amount of calcium-deficient apatite with a ratio of 1.5. It is important to note that TCP cannot be formed by simply mixing calcium and phosphate solutions at a 1.5 ratio; instead, it requires heating calcium-deficient apatite at high temperatures to produce beta TCP, or above 1200°C for alpha TCP.

In summary, the CaP ratio rules the acid-base behavior, solubility, stability, surface area-to-volume ratio, degradation pathways, and its kinetics (34).

On the other hand, osteoinduction is defined as the ability to induce progenitor cells, such as dental pulp stem cells (DPSCs) and regenerative modified dental pulp stem cells (MDPSCs), to differentiate into odontoblast-like cells, which are responsible for dentin formation (35). A related concept is osteoconduction, which refers to the ability of the material to act as a scaffold or template that guides the formation of new bone along its surface. In this process, the surface adsorbs circulating proteins from the biological environment, on which bone cells attach, migrate, proliferate, and differentiate, ultimately leading to matrix production (36).

Both osteoconduction and osteoinduction rely on several factors, including the surface characteristics of CaPs, such as roughness, topography, crystallinity, solubility, composition, and porosity. Some studies have suggested that calcium phosphates are osteoinductive even in the absence of supplements due to their surface chemistry, zeta potential, and isoelectric point. Together with pH, these variables influence protein adsorption, osteoblastic differentiation, and osteointegration. Each CaP phase, such as hydroxyapatite (HA), tricalcium phosphate (TCP), and biphasic calcium phosphate (β-TCP), offers distinct bioactive properties (37).

Although many studies have focused on the osteoconductivity or osteoinductivity of Ca-P bioceramics, the relationship between these two properties remains poorly understood. β-tricalcium phosphate (β-TCP) is one of the most widely used and potent synthetic bone graft substitutes. It is not only osteoconductive, but also osteoinductive. These properties, combined with its cell-mediated resorption, enable complete regeneration of bone defects. However, its clinical outcomes are sometimes considered "unpredictable," likely due to a poor understanding of β-TCP physicochemical properties. In this sense, the β-TCP crystallographic structure has not been fully elucidated. Recent evidence suggests that sintered β-TCP may be coated with a Ca-rich alkaline phase, and a hydrothermal treatment may enhance its apatite-forming ability and osteoinductivity. Moreover, β-TCP grain size and porosity can be significantly modified by trace amounts of β-calcium pyrophosphate or hydroxyapatite impurities (38).

In one study, the osteoconductivity of HA, BCP, and β-TCP was studied based on the osteoblastic differentiation *in vitro* and *in situ*, as well as calvarial defect repair *in vivo*. Osteoinductivity was assessed using pluripotent mesenchymal stem cells (MSCs) *in vitro* and heterotopic ossification in muscles in vivo. Results showed that the cell viability, alkaline phosphatase activity, and the expression of osteogenesis-related genes -including osteocalcin (OCN), bone sialoprotein (BSP), alpha-1 type I collagen (Col1a1), and runt-related transcription factor 2 (Runx2)- ranked as BCP > β-TCP > HA. Conversely, alkaline phosphatase activity and expression of osteogenic differentiation MSCs genes, each ranked as β-TCP > BCP > HA. On the other hand, when tested *in vivo*, calvarial defect implantation of Ca-P bioceramics ranked as BCP > β-TCP ≥ HA, whereas intramuscular implantation ranked as β-TCP ≥ BCP > HA. Further investigation revealed that the Ca/P ratio of the surrounding environment influences both osteoconductivity and osteoinductivity of Ca-P bioceramics. Thus, controlling the appropriate calcium-to-phosphorus release ratio is a critical factor in determining the osteoinductivity potential of Ca-P bioceramics in bone tissue engineering. (39)

The remineralization process begins with nucleation. Nucleation is the transient formation of clusters (Posner Clusters) (40,41), which, once sufficiently large, overcome the thermodynamic barrier and become viable, thereby serving as growth sites for crystal formation.
In turn, the transformation from a liquid aqueous phase to a solid insoluble phase can follow different and complex pathways. Two main processes are generally distinguished, depending on the presence or absence of a pre-existing solid surface, i.e., homogeneous and heterogeneous nucleation. In homogeneous nucleation, the new solid phase forms in the absence of any pre-existing solid surface (e.g., solid bone). Both types of nucleation require solution supersaturation. Additionally, the degree of supersaturation determines the topography, crystal size, and shape of the resulting solid phase. Supersaturation is thus the primary driving force for nucleation. In the case of protein-mineral composites, these principles apply mainly to the mineral component, as proteins are inherently difficult to crystallize.
Heterogeneous nucleation follows a different mechanism that requires the presence of a solid surface. When this surface meets certain conditions, strong

epitaxial growth may occur. If this surface does not permit epitaxy, the newly formed solid may still deposit, but the binding is weak. It is important to note that this description depicts only initial and final states, but the underlying chemical process can be considerably more complex. This phenomenon has been described by Ostwald's rule of stages, also known as the Ostwald-Lussac rule, which states that systems frequently undergo phase or chemical transformations, beginning with the least stable and often the most soluble phase, before transitioning through a series of intermediate steps that culminate in the most thermodynamically stable phase.
In the case of CaP, this sequence begins with the formation of MCPM. Then it proceeds through successive CaP phases, such as brushite, ultimately forming apatite -in the absence of fluoride ions. In intercellular fluids, the mechanism is clearly heterogeneous due to the presence of numerous particles acting as foreign nucleating agents. This pathway is considerably easier than homogeneous nucleation.
It is feasible to obtain non-stoichiometric apatite from brushite aqueous solutions at alkaline pH. However, the amount of calcium-deficient apatite formed will be limited, as indicated by the low Ca/P molar ratio (0.5), which suggests that calcium is the limiting reactant. When additional calcium or alkaline cations are present, the mass of apatite increases. (42)

During the dissolution process, CaPs release calcium (Ca^{2+}) and phosphate (PO_4^{3-}) ions through solution-protein and cell-mediated mechanisms, resulting in the ionic transfer of calcium and inorganic phosphate from the solid to the liquid phase (43). This release modulates extracellular concentrations of Ca^{2+} and PO_4^{3-}. These ions are sensed by cells through a Ras/Ref/ERK-dependent pathway or an adenosine-governed mechanism exerting control over cellular functions (33). Calcium ions provide powerful extracellular signals for odontoblast differentiation (44), while PO_4^{3-} favors enhanced RANKL-RANK binding, leading to heightened nuclear factor kappa B (NF-κB) signaling. This cascade promotes robust dentin differentiation and further supports dentin modeling. (33)

CaPs appear to influence angiogenesis -a crucial process for the efficient transport of various nutrients, chemokines, inflammatory cells and cytokines- and stimulate the differentiation of vascular mesenchymal stem cells and vascular lining resident stem cells (VW-MSCs) and odontoblast like cell differentiation (33, 43) Functioning capillary network of proangiogenic factors delivery such as vascular endothelial growth factor (VEGF) (35), basic fibroblast growth factor (bFGF) and Platelet-derived growth factor (PDGF). Actually, CaP doping with elements such as Strontium, Copper, Cobalt, Iron, Magnesium, and Gold could allow greater control of the repair and regeneration mechanisms of dentin (33, 43, 45).

Additionally, CaPs increase pH and enhance BMP-2 expression at both the mRNA and protein levels, as well as BMP-2 promoter activity. BMP-2 is a crucial regulator of odontogenic differentiation and has been shown to stimulate odontoblast differentiation, as well as the formation of mineralized nodules and dentin, both *in vitro* and *in vivo* (46)

Depending on the environment induced within the dental pulp, calcium phosphate (CaP) materials can stimulate the differentiation of dental pulp stem cells (DPSCs) into specific neuronal cells in the nervous system. Exposure to CaP materials has been shown to induce DPSCs to differentiate into neuron-like cells that not only exhibit neuronal characteristics but also express neural markers and display functional neuronal properties (47). This process can be influenced by calcium and neurotrophic growth factors, such as nerve growth factors (NGF), which play a key role in the development, maintenance, and repair of the nervous system.

Dentin mineralization is a complex process involving the interplay of collagen, calcium phosphate, and various non-collagenous proteins, each contributing distinct roles to the formation of hard tissue. Among the roles these three proteins play in dentin mineralization, the following can be listed: 1) dentin matrix protein (DMP1) may act as both a signaling molecule and nucleator; 2) dentin phosphoprotein (DPP) is crucial for calcium phosphate nucleation; and 3) dentin sialoprotein (DSP) may contribute to the mechanical properties of the dentin-enamel junction.

DMP-1, a tooth-specific phosphoprotein, was first identified in the mineralized dentin matrix. Its fundamental role in hydroxyapatite nucleation within the collagen matrix of bone and dentin during mineralization is attributable to its acidic nature and its ability to bind calcium ions. The presence of DMP-1 and dentin sialophosphoprotein (DSPP) throughout development suggests that these proteins are necessary for maintaining dentin matrix.

In contrast, osteocalcin (OCN) is involved in the inhibition of mineralization. OCN has been shown to bind calcium ions through its γ-carboxyglutamic (GLA) residues, thereby preventing phosphate binding to hydroxyapatite crystals and hindering crystal growth. (16)

González et al. demonstrated that the ALP activity of the experimental material (QCP5) was comparable to that of the control group and MTA. This suggests that the pH generated by the material remained within the necessary range for mineralization, preventing inhibition of ALP expression by excessively alkaline pH conditions (1,3).

Despite broad evidence of the benefits of extracellular calcium for cell differentiation and remineralization, Li et al. conducted a study on third molars showing that cells exposed to calcium exhibited enhanced odontoblast differentiation. However, these cells reported reduced ALP expression on control days 14 and 21, while still demonstrating higher mineralized matrix deposition (24). This phenomenon may be explained by the fact that calcium stimulates ALP activity— a marker of odontoblast-like cell differentiation and function—during the initial days. After this proliferative phase, ALP activity decreases, and the formation of the mineralized matrix appears to proceed independently of this protein. Hence, it is believed that ALP is required to trigger mineralization, but not indispensable for subsequent calcification processes. Nevertheless, its specific role remains unclear (25)

This literature review compiled the available data to address the objective of this study. The various ions and material components cited are expected to act either independently within a single composition or in symbiotic combination.

Conclusion

Calcium phosphates promote the proliferation and differentiation of pulp stem cells into odontoblast-like cells, which are primarily responsible for pulp repair and regeneration. The ions released into the medium—such as calcium, magnesium, phosphate, and hydroxyl—have been shown to contribute to pH regulation, the expression of proteins including ALP, OCN, DMP-1, DSPP, COL1A1, and MEPE, as well as mineralization, and the formation of hydroxyapatite and dentin.

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REVIEW ARTICLES

Applications and performance of artificial intelligence in dentistry and dental materials a scoping review

Background/purpose: *Artificial intelligence (AI) has experienced rapid expansion in biomedical sciences, with increasing integration into dental practice and dental materials research. This scoping review aimed to provide a concise and structured overview of recent advances in AI and to identify the techniques employed in dentistry and dental materials science to enhance diagnosis, accuracy, detection, and clinical decision-making.*

Materials and methods: *A comprehensive electronic search was conducted in ScienceDirect, PubMed/MEDLINE, and Scopus for studies published between 2020 and 2025. Original research articles investigating AI applications in various dental specialties and dental materials science were screened according to predefined inclusion criteria. Thirty studies met the eligibility criteria and were included in this review. Data were extracted and synthesized based on study characteristics, AI techniques used, assessment methods, reported outcomes, and methodological quality.*

Results: *AI technologies have been widely implemented across multiple dental specialties, including restorative dentistry, prosthodontics, endodontics, orthodontics, oral and maxillofacial surgery, implantology, periodontology, and dental materials science. Deep learning models-particularly convolutional neural networks (CNNs)— were the most frequently applied techniques. Across studies, AI systems demonstrated high diagnostic accuracy, improved detection sensitivity, enhanced workflow efficiency, and promising predictive performance in treatment planning and biomaterial optimization.*

Conclusion: *Artificial intelligence represents a transformative advancement in dentistry. Current evidence indicates that AI-based systems significantly improve diagnostic precision and support clinical decision-making. However, despite their high performance, AI technologies remain complementary tools and cannot fully replace human expertise. Continued development, validation, and responsible clinical integration are essential for their future implementation in patient-centered dental care.*

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Introduction

Artificial intelligence (AI) has rapidly evolved over the past decades and is now transforming biomedical research and clinical practice. In dentistry, the integration of AI technologies has accelerated significantly, driven by advances in digital imaging, computational power, and data availability. (1) AI-based systems are increasingly applied to diagnostic imaging, treatment planning, predictive modeling, and workflow automation. (2)

Artificial intelligence encompasses several subfields, including machine learning (ML), deep learning (DL), and artificial neural networks (ANNs).(3) Among these, deep learning—particularly convolutional neural networks (CNNs)—has demonstrated remarkable performance in medical and dental image analysis.(4) These models are capable of automatically extracting complex features from radiographs, cone-beam computed tomography (CBCT), intraoral scans, and clinical photographs, enabling enhanced detection and classification of pathological conditions.(5)

In dentistry, AI applications span multiple specialties, including restorative dentistry, endodontics, orthodontics, oral and maxillofacial surgery, implantology, periodontology, prosthodontics, and dental materials science.(6) Reported applications include automated detection of dental caries, periapical lesions, periodontal bone loss, temporomandibular joint disorders, implant failure prediction, cephalometric landmark identification, prosthetic design optimization, and biomaterial performance prediction.(7)

In recent years, the number of publications exploring artificial intelligence in dentistry has increased substantially, reflecting growing scientific and clinical interest. However, reported applications vary considerably in terms of study design, dataset size, validation protocols, and performance metrics. (8) This heterogeneity makes it challenging to draw comprehensive conclusions regarding the most effective AI techniques and their true clinical applicability.(9) A structured mapping of the existing evidence is therefore essential to identify prevailing trends, methodological gaps, and areas requiring further investigation.(10)

Despite the rapid expansion of research in this field, AI applications in dentistry remain heterogeneous in terms of methodologies, validation strategies, and clinical integration.(11) The growing number of studies highlights the need for a structured synthesis to clarify which AI techniques are currently employed and how they contribute to improving diagnostic accuracy, detection sensitivity, and decision-making processes.(12)

Therefore, the aim of this scoping review was to identify the artificial intelligence techniques used in dentistry and dental materials science and to evaluate their applications and performance in enhancing diagnosis, accuracy, detection, and clinical decision-making.

Materials and methods:

Focused question and study design

This scoping review was conducted and reported in accordance with the PRISMA-ScR (Preferred Reporting Items for Systematic Reviews and Meta-Analyses extension for Scoping Reviews) guidelines. The present analysis was guided by the following research question: "Which artificial intelligence techniques are employed in dentistry and dental materials science to enhance diagnosis, accuracy, detection, and decision-making processes?".

This review aimed to explore the influence of artificial intelligence (AI) across various branches of dentistry, including restorative dentistry, endodontic, orthodontics, oral and maxillofacial surgery, dental implantology, and dental materials science.

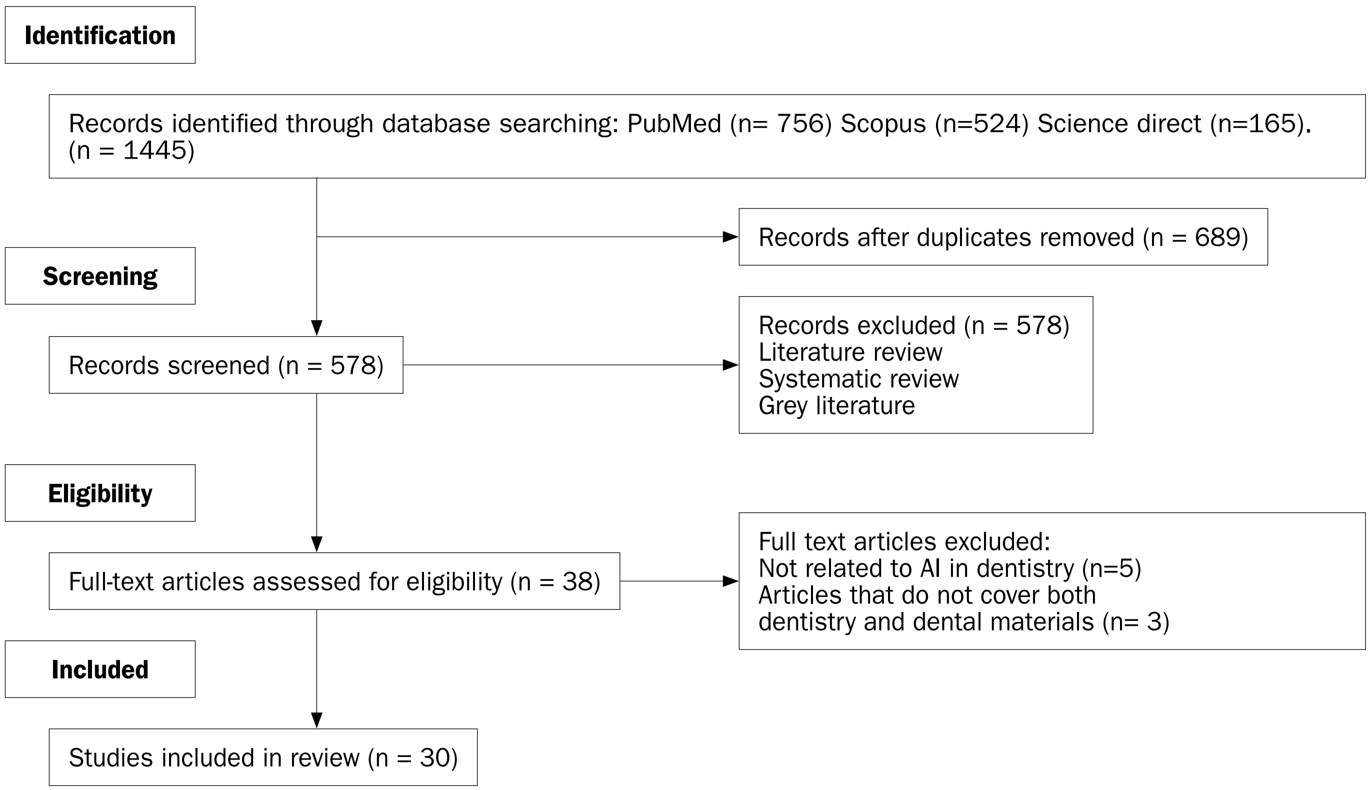

Figure 1
The PRISMA flow diagram for the literature search conducted in this study.

Eligibility Criteria

Relevant articles were selected according to predefined inclusion criteria:

1) Articles written in English,
2) Articles published between 2020 and 2025,
3) Original research articles related to artificial intelligence in dentistry,
4) Prospective studies,
5) Clinical trials,
6) Studies related to advances in dental materials,
7) In vitro investigations involving AI applications.

Exclusion criteria

- Letters to the editor, editorials and comments, grey literature, case reports, and articles related to other medical specialties.
- Full texts of eligible studies were retrieved and analyzed. Data extraction focused on study characteristics, AI techniques used, assessment methods, and reported outcomes.

Search strategy

The electronic search was conducted using the following databases:

- Science Direct
- PubMed/MEDLINE
- Scopus

The search targeted articles published between 2020 and 2025. A free-text search strategy was applied using combinations of the following keywords: (Artificial intelligence), (AI in dentistry),(machine learning), (deep learning), (neural networks), (dental medicine), (dental biomaterials).
To ensure comprehensiveness, references of selected articles were manually screened. Titles and abstracts were carefully reviewed for relevance.

Study selection process

The screening process was conducted by the authors. Titles and abstracts were evaluated for eligibility, and full-text articles were assessed when necessary. Discrepancies were resolved through

First author and date of publication	Scope of application	Objective of the study	No. of images/ photographs for testing	Assessment methods	Results
Kuwada C (2020) (13)	oral and maxillofacial surgery	This study aimed to verify and compare the performance of three deep learning systems when classifying supernumerary teeth on panoramic radiographs.	550 panoramic radiographs	Three learning models were created by using AlexNet, VGG-16, and DetectNet	The results showed that, in general, DetectNet produced the highest values for diagnostic accuracy
Lee J H (2020) (14)	Oral Pathology	Evaluating fully deep convolutional neural network method (R-CNN) for automated tooth segmentation on panoramic radiographs is the focus of this study.	846 images	deep learning method using the mask R-CNN model was implemented	Panoramic dental images were successfully automated using the proposed method, that performed excellently
S Yamaguchi (2020) (15)	restorative materials	This study aimed to evaluate the usefulness of the convolutional neural network (CNN) deep learning method for predicting the probability of CAD/ CAM composite resin crown detachment.	8 640 images	convolutional neural network (CNN)	This study that demonstrated excellent performance in predicting the probability of CAD/ CAM crown detachment using 3D stereolithography models of dies scanned from patients
KS Lee (2020) (16)	oral and maxillofacial surgery	The aim of the present study was to develop an artificial intelligence (AI) based diagnostic tool with the capacity for automatic detection of temporomandibular joint (TMJ) osteoarthritis from cone beam computed tomography (CBCT) image.	3 514 images CBCT	deep neural network model. (RNN)	The employment of a deep The employment of a deep neural network model has enabled the automated detection of ATM from sagittal CBCT image.
Anselmo Garcia Cantu (2020) (17)	Periodontics	The utilization of deep learning algorithms for the identification of radiographic caries lesions.	3686 radiographs	applied a convolutional neural network (U-Net)	It has been demonstrated that deep neural networks exhibit a higher degree of accuracy in identifying carious lesions when compared to the dentists.
Mengxun Li (2020) (18)	cosmetic dentistry	The objective of this study is to develop an automated system that will enable the efficient labeling and integration of information into facial and intraoral images	50 images	The system relies on ROI detection, tooth segmentation, and registration.	The proposed algorithm demonstrated an 96.0% (263/274) recognition rate of teeth. The findings of this study demonstrate that the proposed automated system facilitates dentists in circumventing the arduous image integration process.

Table 1A

First author and date of publication	Scope of application	Objective of the study	No. of images/ photographs for testing	Assessment methods	Results
Félix Kunz (2020) (19)	orthodontics	The study compared AI- generated cephalometric radiographs with those of human experts.	1792 cephalometric radiographs	Use of a customized convolutional neural network	Almost no statistically significant differences were found between AI assessments and the human reference method.
Yoshiko Ariji (2020) (20)	Oral and maxillofacial surgery	This study aims to clarify the diagnostic performance of computed tomography. This is in the extranodal extension of cervical lymph node metastases. The study uses deep learning classification.	703 CT images	Five learning models were created using a neural network "AlexNet"	In terms of extranodal extension, the diagnostic performance of deep learning was significantly superior to that of radiologists. Deep learning achieved an accuracy of 84.0% for extranodal extension.
Henriette Lerner (2020) (21)	Dental material	The present study has been devised for the purpose of outlining a protocol for the use of artificial intelligence in the fabrication of monolithic zirconia crowns (MZC)	106 implant-supported MZC	based on the proprietary ScanPlanMakeDone protocol.	The results demonstrated that following the implementation of the MZC, the quality of fit, interproximal and occlusal contact, and aesthetic integration, were all found to be excellent.
Toshihito Takahashi (2021) (22)	Prosthodontic	A convolutional neural network (CNN) method has been developed for the classification of images of partially edentulous arches.	1184 images	A CNN method for classifying images has been developed.	The employment of a convolutional neural network (CNN) has facilitated the classification and prediction of dental arches. The diagnostic accuracy was 99.5% for the maxilla and 99.7% for the mandible
Kühnisch J (2021) (23)	caries diagnostics	The aim of this diagnostic study was twofold. Firstly, a deep learning approach with convolutional neural networks (CNNs) was developed for caries detection and categorization. Secondly, the diagnostic performance was compared with respect to expert standards.	2.417 anonymized photographs	Develop a deep learning approach with convolutional neural networks (CNNs)	The present study demonstrated that the CNN demonstrated an 92.5% success rate in accurately identifying caries in images.

Table 1B

First author and date of publication	Scope of application	Objective of the study	No. of images/ photographs for testing	Assessment methods	Results
Frank C Setzer (2021) (24)	endodontic	This study set out to achieve two key objectives. Firstly, a deep learning (DL) algorithm was used to automate the segmentation of cone-beam computed tomography (CBCT) images. Secondly, it aimed to detect periapical lesions.	Cone beam computed tomography (CBCT) images n = 20	Application of a deep learning (DL) algorithm	The DL algorithm has demonstrated excellent results in terms of lesion detection accuracy.
Chihiro Tanikawa (2021) (25)	orthodontic treatment	The objective of the present study was to develop two artificial intelligence (AI) systems with the capability to predict three-dimensional facial topography subsequent to orthognathic surgery and orthodontic treatment	137 oral photographs	The development of two AI systems that combine deep learning and a genetic model (GMM)	The system for predicting facial morphology after treatment was successfully developed using a combination of GMM and deep learning.
Qiwen Cui, BS (2021) (26)	prosthodontics	The objective of this prospective study to construct a computerized decision support (CDS) model that utilizes electronic dental records to predict dental extraction treatment.	4135 EDRs (electronic dental records)	CDS model	The CDS model employed for the purpose of dental extraction treatment has demonstrated a high level of proficiency in terms of decision-making as evidenced by the analysis of EDRs.
Hamdan MH (2022) (27)	Dentomaxillofacial	The present study aims to examine the efficacy of utilizing the Denti.AI system in assisting dentists in the detection of apical radiolucencies on periapical radiographs.	Sixty-eight intraoral periapical radiographs	Denti.AI system	The study demonstrated that the DL technology (Denti. AI) has the capacity to augment the capabilities of dental professionals in detecting apical radiolucencies in intraoral radiographs
Preda F (2022) (28)	Oral diseases	The present study investigated the accuracy consistency and time efficiency of a novel deep convolutional neural network (CNN) model for automated maxillofacial bone segmentation.	144 scans	A three-dimensional (3D) U-Net (CNN) model was developed, and the automated segmentation obtained was compared to a manual approach.	It is recommended that the proposed CNN model be used for the efficient, accurate and consistent automated segmentation of the maxillofacial complex using CBCT data.

Table 1C

First author and date of publication	Scope of application	Objective of the study	No. of images/ photographs for testing	Assessment methods	Results
Pavel Alekseevich Lyakhov (2022) (29)	Dental Implantology	The objective of this study is to develop a neural network system to evaluate the survival of dental implants.	1 646 oral photographs	Optimal linear neural network topologies have been developed on the basis of research into their functionality.	The results demonstrated that the neural network system developed possesses the capacity to predict the positive or negative outcome of a single implant procedure, however, its application as a comprehensive medical aid tool remains unfeasible.
Mihee Hong (2022) (30)	Orthodontics	Creation of an AI-based model for precise landmark identification in serial lateral cephalometric radiographs of class III patients who have had orthodontic treatment and orthognatic surgery.	302 digitized panoramic radiographs	algorithme de réseau neuronal convolutif (CNN)	The total mean error was 1.17 mm. the cascaded convolutional neural network (CNN) algorithm proposed in this study demonstrated the potential for identifying landmarks from bone anatomy in lateral cephalograms.
Xuan Zhang (2022) (31)	Oral diseases	The development and evaluation of a deep learning system employing a convolutional neural network (ConvNet) for the purpose of detecting the presence of dental caries in oral photographs will be conducted.	3,932 oral photographs	A deep ConvNet was developed by adapting the singles shot MultiBox detector. The hard negative exploration algorithm was applied to automatically train the model.	The utilization of deep learning model has demonstrated considerable potential in the identification of dental caries in oral photographs.
Chunan Zhang (2023) (32)	Dental implant	The objective of this study was to develop a deep learning-based model for predicting dental implant failure.	529 periapical images	.ResNest-50 deep convolutional neural network (CNN)	The deep learning model exhibited an 87% prediction accuracy for implant malfunction
Zhang Yimeng (2023) (33)	pediatric dentistry	This study aimed to develop a machine learning model to determine the prevalence of molar incisor hypomineralisation (MIH) among children living in a region of central China affected by endemic fluorosis.	1568 samples	In this study, supervised machine learning and correlation analysis were used.	The incidence of MIH dereased with increasing severity of dental fluorosis (DF), as shown by the nomogram.

Table 1D

First author and date of publication	Scope of application	Objective of the study	No. of images/ photographs for testing	Assessment methods	Results
Anastasia Grymak (2023) (34)	Dental material	The aim of study is to develop algorithms that can predict the in vitro wear resistance of conventional prosthetic teeth that have been machined using CAD and printed in 3D.	Six prosthetic tooth materials	An LSTM model was developed	The LSTM model was successfully developed. It can reduce the duration of simulations. It can also reduce the number of samples required for wear testing of various dental materials.
Jun-Ho Cho (2024) (35)	restorative dentistry	A comparative analysis was conducted of the dental morphology, internal fit, occlusion, and proximal contacts of dental crowns generated by conventional software with two deep learning (DL)- based dental software systems	30 scans	The crowns were designed using two DL methods (AA and AD) and one technician method (NC).	The results indicated that the variations observed were attributable to internal adjustment, occlusion, and proximal contacts.
Seung-Hwan Ong (2024) (36)	forensic odontology	Utilizing deep learning and adopting Demirjian's methodology, this study endeavours to a dental development staging system.	5,133 panoramic radiographs	The proposed methodology includes three CNN model procedures: the Yolov5 detection model, U-Net, and EfficientNet.	The proposed deep learning approach can serve as a support tool for dentists.
Rabia Karakuş (2024) (37)	restorative dentistry	The objective of this study was to develop a system for the detection and classification of dental caries that is based on deep learning.	860 interproximal radiograph	The AI-based learning process was performed using the YOLOv8 algorithm.	The success rate for detecting occlusal, secondary, and interproximal caries was high, with an accuracy of 97.7% and a recall of the mean score was 93.2%, and the F1 score was 95.4%
Oana-Maria Butnaru (2025) (38)	Periodontology	The objective of this comparative study was to compare AI-assisted dental and periodontal diagnoses with those made by specialists and general dentists.	Six radiological images	The AI system used for diagnosis (Planmeca Romexis, version 6.4.7, Helsinki, Finland).	AI systems have significant potential as reliable tools for dental and periodontal assessment, complementing the expertise of human practitioners.
Allihaibi M (2025) (39)	endodontics	Evaluation of the performance of the diagnostic at AI platform in assessing endodontic treatment results on periapical radiographs compared to that of experienced clinicians.	376 teeth	IA (Diagnocat)	The results showed that evaluation of endodontic treatment outcomes requires clinical monitoring, and that the AI- driven platform is a complementary tool.

Table 1E

First author and date of publication	Scope of application	Objective of the study	No. of images/ photographs for testing	Assessment methods	Results
Yunus Balel (2025) (40)	Dental implantology	The objective of this study was to develop a deep learning model based on artificial intelligence (AI) that is capable of detecting and number implants.	32585 panoramic radiographs	deep learning models compared: YOLOv8, RetinaNet, Faster R-CNN, DETR, U-Net, Mask R-CNN, and DeepLab v3+	The AI model exhibiteb a high degree of accuracy in the detection and enumeration of dental implants in panoramic radiographs.
Pul U (2025) (41)	endodontics	Detection of periapial radiolucenies (PR) with and without artificial intelligence.	50 panoramic radiographs	dentalXrai Pro The software uses a convolutional neural network (CNN) architecture.	The use of AI assistance slightly improved the detection of periapical radiolucencies (RP), with junior dentists showing the most significant improvement.
Paniagua K (2025) (42)	Dental material	The aim of this study is to evaluate the effectiveness of AI models in predicting organoleptic properties (OP) in order to develop more sustainable composites while reducing time, effort and costs.	233 samples	Nine ML classification algorithms [SVM], Decision Tree, KNN classifier, [LGBM], Random Forest, Logistic Regression, Gaussian Naïve Bayes, [ELM], and [XGBoost])	Different AA models achieved better results depending on performance, with some performing better than others.

Table 1F

Table 1A-1F
The studies that have used AI based models in various specialties of dentistry and Dental material.

discussion and consensus. The study selection process is illustrated in the PRISMA flow diagram.

Risk of Bias assessment

Although this review followed a scoping methodology, the methodological quality of the included studies was assessed qualitatively. Risk of bias was evaluated based on study design, sample size, validation methodology, dataset characteristics, and clarity of outcome reporting. Studies were categorized as having low, moderate, or high risk of bias accordingly.

Results

Study selection

The electronic search initially identified 1445 records (PubMed: 756; Scopus: 524; ScienceDirect: 165). After removal of duplicates and screening of titles and abstracts, 38 full-text articles were assessed for eligibility. Eight articles were excluded for not meeting the inclusion criteria. Ultimately, 30 studies published between 2020 and 2025 were included in this scoping review. The study selection process is illustrated in the PRISMA flow diagram.

General characteristics of included studies

The included studies covered multiple dental specialties, including oral and maxillofacial surgery, restorative dentistry, prosthodontics, endodontics, orthodontics, periodontology, dental implantology, pediatric dentistry, forensic odontology, and dental materials science.
Most investigations focused on imaging-based applications, particularly panoramic radiographs, cone-beam computed tomography (CBCT), intraoral radiographs, and oral photographs.
Deep learning models-especially convolutional neural networks (CNNs)-were the most frequently employed artificial intelligence techniques. Other reported approaches included

machine learning algorithms, recurrent neural networks (RNNs), long short-term memory (LSTM) models, object detection models (YOLO, Mask R-CNN), and clinical decision-support systems.

Diagnostic and predictive performance

The majority of studies evaluating AI in radiographic interpretation reported high diagnostic performance. Accuracy values frequently exceeded 85%, with several studies demonstrating results comparable to or exceeding those of experienced clinicians in detecting dental caries, periapical lesions, periodontal bone loss, temporomandibular joint disorders, and maxillofacial pathologies.

In implantology, predictive models for implant survival and failure demonstrated accuracy rates ranging approximately from 84% to 87%. Automated implant detection systems also showed high reliability in identifying and numbering implants on panoramic radiographs.

In orthodontics, AI-assisted cephalometric landmark identification achieved clinically acceptable precision, with reported mean errors close to 1mm. Systems developed for facial morphology prediction and growth assessment demonstrated promising predictive capabilities.

In prosthodontics, AI-based CAD/CAM systems achieved high accuracy in classifying partially edentulous arches and designing dental crowns.

In dental materials science, machine learning models successfully predicted wear resistance, debonding probability, and composite material performance, supporting accelerated biomaterial optimization.

Overall findings

Overall, the findings indicate that artificial intelligence applications in dentistry predominantly enhance diagnostic accuracy, detection sensitivity, workflow efficiency, and predictive modeling. Across specialties, AI systems consistently demonstrated high performance, particularly in imaging-based tasks and decision-support applications.

Discussion and conclusion

The present scoping review aimed to identify which artificial intelligence techniques are employed in dentistry and dental materials science and to evaluate how these technologies enhance diagnosis, accuracy, detection, and clinical decision-making processes.

The analysis of the included studies demonstrates that the most frequently used artificial intelligence techniques are machine learning (ML) and deep learning (DL) models, particularly convolutional neural networks (CNNs). Other architectures such as recurrent neural networks (RNNs), long short-term memory (LSTM) models, decision-support systems, and object detection algorithms (e.g., YOLO, Mask R-CNN) were also reported.(43) Overall, AI systems were mainly applied to imaging-based diagnostics, predictive modeling, digital workflow automation, and biomaterial optimization.

AI in diagnostic imaging and disease detection

The majority of the included studies focused on radiographic interpretation. CNN-based systems showed high diagnostic performance in detecting dental caries, periapical lesions, periodontal bone loss, temporomandibular joint disorders, maxillofacial pathologies, and Implant-related complications.

Several investigations reported that AI –assisted diagnosis improved clinician's performance, particularly among less experienced practitioners.(44) These findings suggest that AI enhances diagnostic accuracy, reduces inter-operator variability, and increases reproducibility. However, AI systems function primarily as clinical decision-support tools rather than replacing human expertise.

AI in dental implantology

AI in dental implantology represents one of the most rapidly expanding application fields of artificial intelligence in dentistry. Neural network systems and deep learning models have been developed to predict implant survival, detect implant failure from panoramic and periapical radiographs, and automatically identify and number implants. These predictive approaches contribute to improved risk assessment, prognosis estimation, and treatment planning. The integration of AI into implant workflows reflects a shift toward more data-driven and personalized therapeutic strategies. (45)

AI in orthodontics and craniofacial analysis

In orthodontics, AI applications mainly involve automated cephalometric landmark detection, growth and developmental assessment, and prediction of facial morphology after orthognathic surgery. CNN-based systems demonstrated accuracy comparable to experienced orthodontists while offering improved consistency and time efficiency. The ability of AI systems to reproduce landmark positioning with minimal variability may contribute to treatment standardization and improved longitudinal monitoring.

AI in prosthodontics and digital workflows

In prosthodontics, deep learning models have been integrated into CAD/CAM systems for classification of partially edentulous arches, crown morphology design, and automated integration of intraoral and facial images. These technologies enhance workflow automation, improve precision, and reduce manual workload in restorative procedures.
The synergy between AI and digital dentistry represents a major advancement toward semi-automated restorative planning and fabrication.

AI in dental materials science

In recent years, there has been an increased interest in biomaterials for dental applications, with many new biomaterials being introduced for these purposes (46). The implementation of artificial intelligence (AI) in materials science has been a subject of considerable interest. Recent advancements in artificial intelligence have led to substantial enhancements in rational design and accelerated the identification of diverse biomaterials (47). In the contemporary era of rapid advancements in data processing and algorithms, machine learning and deep learning have emerged as pivotal methodologies for the identification of novel biomaterials prior to their actual production.
Within dental biomaterials research, machine learning and SLTM-based models have been employed to predict wear resistance, debonding probability, mechanical behavior, and organoleptic properties of restorative materials. AI contributes to accelerating material development, optimizing biomaterial performance, and reducing experimental time and cost.
Recent contributions continue to expand the scope of AI in dentistry. For example, a 2026 study published in Applied Sciences (DOI: 10.3390/app16010396) highlights the integration of explainable artificial intelligence models in dental diagnostics and materials research, emphasizing transparency, interpretability, and clinical applicability AI systems. (48)
The application of artificial intelligence (AI) in conjunction with three-dimensional printing techniques has yielded substantial benefits, particularly in the domain of prosthetics and device fabrication (55) (48). The advent of artificial intelligence (AI) has had a profound impact on the realm of 3D printing, particularly in the domain of manufacturing various types of implants and prosthetics. The combination of artificial intelligence with three-dimensional printing technologies further enhances precision in prosthetic fabrication and material customization.

Methodological considerations and limitations

Notwithstanding the promising findings, several limitations should be acknowledged. Many included studies were retrospective and based on relatively limited datasets, with heterogeneous validation protocols. External validation across different populations and imaging systems remains insufficient.

Furthermore, the complexity of AI systems, implementation costs, data privacy concerns, and ethical considerations must be carefully considered before large-scale clinical adoption. Standardized reporting guidelines and multicenter prospective studies are needed to strengthen the evidence base and enhance generalizability.

Overall, the findings of this review indicate that computerized neural networks and machine learning models provide substantial support for dental practitioners in diagnosis, treatment planning, and outcome prediction. Artificial intelligence is expected to play an increasingly important role in dentistry, particularly in personalized and patient-centered care.

Conclusion

This scoping review demonstrates that artificial intelligence is increasingly integrated across multiple dental specialties, including diagnostic imaging, implantology, orthodontics, prosthodontics, oral pathology, and dental materials science.

The most frequently employed techniques are machine learning and deep learning models, particularly convolutional neural networks, which enhance diagnostic accuracy, improve lesion detection, support treatment planning, and contribute to predictive modeling and biomaterial optimization.

Although many AI systems show performance comparable to human experts, current evidence supports their primarily as clinical decision-support tools rather than autonomous diagnostic systems.

Despite promising results, challenges remain regarding data standardization, external validation, ethical considerations, and cost-effectiveness. Future research should focus on multicenter prospective studies and the development of explainable AI models to facilitate safe and responsible clinical implementation.

Artificial intelligence represents a transformative advancement in dentistry and dental materials science. With continued refinement and interdisciplinary collaboration, AI has potential to significantly improve precision, efficiency, and patient-centered care in modern dental practice.

Conflicts of interest

The authors declare that they have no conflicts of interest.

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Francesco Maggiore
Presidente della Società Italiana di Endodonzia

Lettera DEL PRESIDENTE

Cari Soci della Società Italiana di Endodonzia,

è con rinnovato entusiasmo e profonda gratitudine che vi scrivo all'inizio del secondo anno del mio mandato come Presidente della SIE. Se un anno fa inauguravamo questo percorso con l'orgoglio di chi inizia una nuova avventura, oggi possiamo dire con soddisfazione di avere già percorso insieme un tratto significativo di strada e di poter parlare di primi risultati.

Il 2025 è stato un anno straordinario, reso tale soprattutto da voi, dalla vostra partecipazione attiva al programma culturale che ha trasformato i nostri progetti in realtà vibranti. I numeri ci confortano e ci riempiono di orgoglio: dopo un periodo complesso per la formazione in presenza, abbiamo assistito a una significativa e confortante risalita delle presenze ai nostri eventi culturali. Possiamo dire che tante sale si sono nuovamente riempite, i dibattiti sono tornati ad animarsi, e questo è il segnale più tangibile che la direzione intrapresa è quella giusta e che la voglia di incontrarsi, confrontarsi e crescere insieme è sempre forte.

Tra i successi più significativi di questo primo anno, desidero ricordare la prima edizione del corso Ready to Work. Questa iniziativa, pensata per accompagnare i giovani colleghi e non solo verso l'ingresso nel mondo della pratica endodontica quotidiana con strumenti concreti e immediatamente spendibili, ha riscosso un tangibile successo. Il riscontro ricevuto ci ha inoltre spinto a fare di più e meglio: una nuova edizione del Ready to Work è già in programma, e parallelamente abbiamo deciso di implementare un nuovo corso avanzato, posto un gradino più in alto, chiamato Level up: Ready to Advance, per coloro che desiderano affinare ulteriormente le proprie competenze e affrontare con sicurezza casi clinici di crescente complessità. La formazione clinica a 360 gradi, a tutti i livelli, rimane un pilastro irrinunciabile della nostra missione.

Il momento più alto dell'anno è stato senza dubbio il Congresso Nazionale di Verona. La formula del Clinical Match ha coinvolto la platea in un confronto dinamico e appassionante. I relatori stranieri di fama internazionale hanno portato il loro contributo di altissimo profilo, i giovani colleghi della società hanno dimostrato preparazione e talento. La qualità delle relazioni è stata unanimemente riconosciuta come eccellente, e l'evento sociale ha offerto l'occasione per consolidare le relazioni in un clima disteso e conviviale. La risposta degli sponsor è stata entusiasta, e il numero dei partecipanti ha superato ogni aspettativa: circa 600 presenze hanno animato il congresso, un risultato che ci riempie di orgoglio e ci rassicura sulle scelte compiute.

Il programma culturale per il 2026 è già partito con slancio, e lo ha fatto nel migliore dei modi con il Congresso Poker d'Assi. Questo evento non solo ha riaperto i lavori all'insegna dell'alta formazione, ma ha avuto il merito di sottolineare con forza un concetto a me particolarmente caro: la complementarietà delle discipline odontoiatriche è fondamentale per il successo in Endodonzia. La multidisciplinarietà non è solo uno slogan, ma la chiave di volta per una moderna e consapevole pratica clinica, e questo congresso ne è stato una straordinaria testimonianza.

L' offerta formativa di quest'anno sarà arricchita dai Web in Air monotematici, momenti di approfondimento agile e mirato per rimanere costantemente aggiornati comodamente a casa o in studio. Avremo poi un appuntamento di straordinario rilievo con il Closed Meeting di Ischia, dove ci incontreremo con altre società scientifiche straniere in un'ottica di sempre maggiore apertura internazionale. Sarà come di consueto un'occasione imperdibile per incontrarci in un clima disteso, vivere insieme momenti di aggiornamento, confronto e convivialità.

Il nostro appuntamento clou rimane il Congresso Nazionale, che si terrà a Verona dal 29 al 31 Ottobre 2026 e che quest'anno affronterà un tema cruciale e affascinante: "Il Piano di Trattamento e Possibilità di Recupero dell'Elemento Gravemente Compromesso". Un tema che rappresenta la sfida quotidiana per molti di noi e che mette al centro la capacità diagnostica, la pianificazione strategica e l'integrazione tra competenze diverse per offrire al paziente la migliore soluzione possibile, spingendoci a valutare ogni possibilità di recupero prima di qualsiasi scelta alternativa.

Il programma culturale 2026 è caratterizzato inoltre dalle giornate organizzate dalle Macroaree, che porteranno l'eccellenza SIE in tutto il territorio nazionale, rendendoci sempre più presenti e capillari, replicando il risultato del 2025 che ha registrato 32 eventi su tutto il territorio nazionale.
A questo si aggiunge la fruttuosa collaborazione con AIOM e ANDI, un progetto che sta dando risultati straordinari. Gli eventi sinora organizzati insieme hanno totalizzato più di 800 partecipanti e, con le giornate ancora in programma, ci prefiggiamo di raggiungere le 1000 presenze. L'interesse sempre maggiore ci ha spinto a programmare ulteriori giornate per il 2026, a testimonianza della bontà di questo percorso di collaborazione interdisciplinare.

Una SIE più moderna, dinamica, inclusiva e vicina ai propri soci è possibile. Continuiamo a lavorare insieme con la stessa passione, lo stesso impegno e lo stesso spirito di collaborazione, partecipando numerosi a tutti gli eventi che ci attendono. Ogni vostro contributo è fondamentale per rendere la nostra comunità sempre più forte e rappresentativa.

Vi aspetto numerosi ai prossimi appuntamenti che ci attendono.

Con i migliori saluti,

Il Presidente
Società Italiana di Endodonzia

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COME DIVENTARE SOCIO ATTIVO/AGGREGATO

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

SOCIO AGGREGATO

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

DOCUMENTAZIONE NECESSARIA PER DIVENTARE SOCIO AGGREGATO

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

SOCIO ATTIVO

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

DOCUMENTAZIONE NECESSARIA PER DIVENTARE SOCIO ATTIVO

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

MODALITÀ DI DOCUMENTAZIONE DEI CASI CLINICI

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

CRITERI DI VALUTAZIONE

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

ADEMPIMENTI DEL CANDIDATO

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

PRESENTAZIONE DEI CASI ALLA COMMISSIONE

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

LA COMMISSIONE ACCETTAZIONE SOCI

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

MEMBRI DELLA COMMISSIONE ACCETTAZIONE SOCI BIENNIO 2025-26

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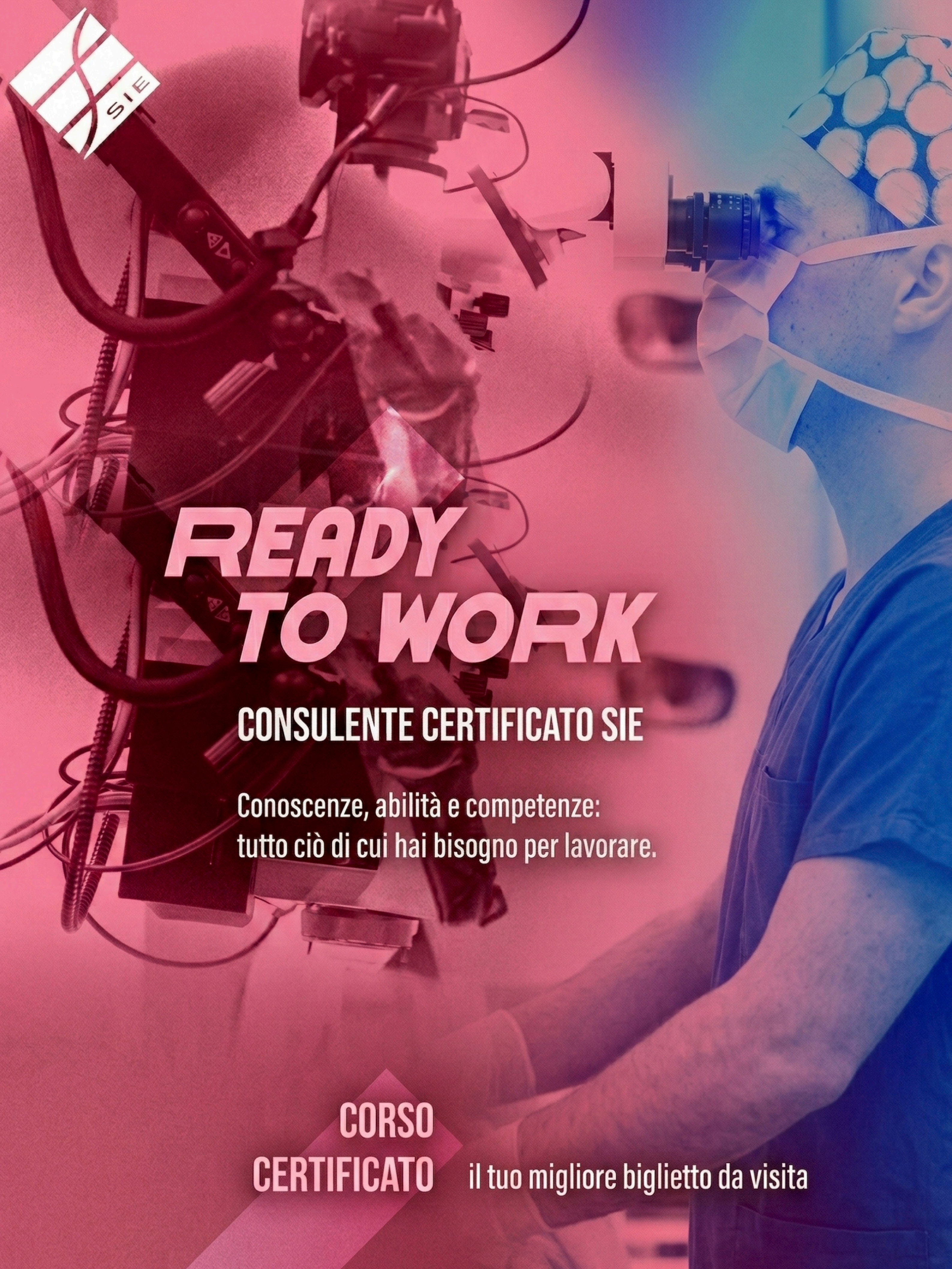
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GUIDELINES FOR AUTHORS

Giornale Italiano di Endodonzia (GIE)
was founded in 1987 and is the official journal of Società Italiana di Endodonzia, SIE (Italian Society of Endodontics) https://www.endodonzia.it/
It is a peer-reviewed journal, only available in electonic format and publishes original scientific articles, reviews, clinical articles and case reports in the field of Endodontology. Scientific contributions dealing with health, injuries to and diseases of the pulp and periradicular region, and their relationship with systemic well-being and health. Original scientific articles are published in the areas of biomedical science, applied materials science, bioengineering, epidemiology and social science relevant to endodontic disease and its management, and to the restoration of root-treated teeth. In addition, review articles, reports of clinical cases, book reviews, summaries and abstracts of scientific meetings and news items are accepted. Please read the instructions below carefully for details on the submission of manuscripts, the journal's requirements and standards as well as information concerning the procedure after a manuscript has been accepted for publication in Giornale Italiano di Endodonzia. Giornale Italiano di Endodonzia is indexed in Scopus, Science Direct, Embase and published online by Tecniche Nuove, Milan, Italy and hosted by PAGEPress, Pavia, Italy. All articles are available on www.giornaleitalianoendodonzia.it.
We publish, monthly, new articles in the Early View section while the full Journal is issued twice a year, in June and November.
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Ethical guidelines
Giornale Italiano di Endodonzia adheres to the below ethical guidelines for publication and research.

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

Manuscript preparation
Manuscripts should be uploaded as Word (.doc) or Rich Text Format (.rtf) files (not write-protected) plus separate figure files: TIF, EPS, JPEG files are acceptable for submission.
The text file must contain the **abstract, main text, references, tables and figure legends**, but no embedded figures or title page. The title page should be provided as a separate file. In the main text, please reference figures as for instance **figure 1, figure 2** etc to match the tag name you choose for the individual figure files uploaded.
Please note that **manuscripts must be written in English**. Authors whose native language is not English are strongly advised to have their manuscript checked by a language editing service or by a native English speaker prior to submission.

Manuscript Types Accepted
Original Scientific Articles must describe significant and original experimental observations and provide sufficient detail so that the observations can be critically evaluated and, if necessary, repeated. Original Scientific Articles must conform to the highest international standards in the field.
Systematic Review Articles reconsider and bring previously published systematic reviews up to date. This allows authors to present changes to the review while avoiding unwarranted duplication in the literature. A guiding principle for an update is that it is an event that is discrete and distinct from the conduct and reporting of the original systematic review (or previously updated review). This means that at a minimum the search for studies will have been brought up to date and that any changes to the results and conclusions of the original review (or a previously updated review) are described. Systematic review updates will not usually warrant publication of a new full-length article. However, any published update will be an independent publication. It will not be part of the original review publication (or previously updated review).
We encourage authors to be innovative in how they report and present systematic review updates. Systematic review updates are not appropriate for corrections/errata. Authors must clearly acknowledge and reference any previously-published work they are updating.
Review Articles are accepted for their broad general interest; all are refereed by experts in the field who are asked to comment on issues such as timeliness, general interest and balanced treatment of controversies, as well as on scientific accuracy. Reviews should generally include a clearly defined search strategy and take a broad view of the field rather than merely summarizing the authors´ own previous work. Extensive or unbalanced citation of the authors´ own publications is discouraged.
Mini Review Articles are accepted to address current evidence on well-defined clinical, research or methodological topics. All are refereed by experts in the field who are asked to comment on timeliness, general interest, balanced treatment of controversies, and scientific rigor. A clear research question, search strategy and balanced synthesis of the evidence is expected. Manuscripts are limited in terms of word-length and number of figures.
Clinical Articles are suited to describe significant improvements in clinical practice such as the report of a novel technique, a breakthrough in technology or practical approaches to recognised clinical challenges. They should conform to the highest scientific and clinical practice standards.
Case Reports or **Case Series** illustrating unusual and clinically relevant observations are acceptable, but they must be of sufficiently high quality to be considered worthy of publication in the Journal. On rare occasions, completed cases displaying nonobvious solutions to significant clinical challenges will be considered. Illustrative material must be of the highest quality and healing outcomes, if appropriate, should be demonstrated.
Case reports should be written using the **Preferred Reporting Items for Case reports in Endodontics (PRICE) 2020 guidelines.** A PRICE checklist and flowchart (as a Figure) should also be completed and included in the submission material. The PRICE 2020 checklist and flowchart can be downloaded from: http://pride-endodonticguidelines.org/price/. It is recommended that authors consult the following papers, which explains the rationale for the PRICE 2020 guidelines and their importance when writing manuscripts:

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

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

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

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

I. Title, which should be concise as well as descriptive (no more than 150 letters and spaces);
II. Initial(s) and last (family) name of each author;
III. Name and address of department, hospital or institution to which the work should be attributed;
IV. Running title (no more than 30 letters and spaces);
V. Three to five key words (in alphabetical order);
VI. Name, full postal address, telephone, fax number and e-mail address of author responsible for correspondence (Corresponding Author).

Abstracts should be no more than 250 words giving details of what was done.

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

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

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

Abstract for Mini Review Articles should be non-structured of no more than 250 words, including a clear research question, details of the literature search strategy and clear conclusions.

Abstract for Case Reports and **Case Series** should be no more than 250 words using the following structure.
Aim: give a clear statement of the main aim of the report and the clinical problem which is addressed.
Summary: describe the methods adopted including, as appropriate, the design of the study, the setting, entry requirements for subjects, use of materials, outcome measures and analysis if any.
Key learning points: provide up to five short, bullet-pointed statements to highlight the key messages of the report. All points must be fully justified by material presented in the report.

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

THE STRUCTURE

Main text for Original Scientific Articles should include Introduction, Materials and Methods, Results, Discussion and Conclusion.
Introduction: should be focused, outlining the historical or logical origins of the study and gaps in knowledge. Exhaustive literature reviews are not appropriate. It should close with the explicit statement of the specific aims of the investigation, or hypothesis to be tested.
Material and Methods must contain sufficient detail such that, in combination with the references cited, all clinical trials and experiments reported can be fully reproduced.
(I) Clinical Trials: should be reported using the CONSORT guidelines available at www.consort-statement.org A CONSORT checklist and flow diagram (as a Figure) should also be included in the submission material.
(II) Experimental Subjects: experimentation involving **human subjects** will only be published if such research has been conducted in full accordance with ethical principles, including the World Medical Association Declaration of Helsinki (version 2008) and the additional requirements, if any, of the country where the research has been carried out. Manuscripts must be accompanied by a statement that the experiments were undertaken with the understanding and written consent of each subject and according to the above mentioned principles. A statement regarding the fact that the study has been independently reviewed and approved by an ethical board should also be included. Editors reserve the right to reject papers if there are doubts as to whether appropriate procedures have been used. When **experimental animals** are used the methods section must clearly indicate that adequate measures were taken to minimize pain or discomfort. Experiments should be carried out in accordance with the Guidelines laid down by the National Institute of Health (NIH) in the USA regarding the care and use of animals for experimental procedures or with the European Communities Council Directive of 24 November 1986 (86/609/EEC) and in accordance with local laws and regulations. All studies using human or animal subjects should include an explicit statement in the Material and Methods section identifying the review and ethics committee approval for each study, if applicable. Editors reserve the right to reject papers if there is doubt as to whether appropriate procedures have been used.
(III) Suppliers of materials should be named

and their location (Company, town/city, state, country) included.
Results should present the observations with minimal reference to earlier literature or to possible interpretations. Data should not be duplicated in Tables and Figures.
Discussion may usefully start with a brief summary of the major findings, but repetition of parts of the abstract or of the results section should be avoided. The Discussion section should progress with a review of the methodology before discussing the results in light of previous work in the field. The Discussion should end with a brief conclusion and a comment on the potential clinical relevance of the findings. Statements and interpretation of the data should be appropriately supported by original references.
Conclusions should contain a summary of the findings.

Main Text of Systematic Review Articles

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

Main Text of Review Articles

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

Main Text of Mini Review Articles

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

Main Text of Case Reports and Case series

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

IMPORTANT TO KNOW

Manuscript that do not conform to the general aims and scope of the Journal will be returned immediately without review. All other manuscripts will be reviewed by experts in the field (generally two referees). Giornale Italiano di Endodonzia aims to forward referees´ comments and to inform the corresponding author of the result of the review process. Manuscripts will be considered for fast-track publication under special circumstances after consultation with the Editor. Giornale Italiano di Endodonzia uses **double blinded review** which menas that the names of the reviewers will thus not be disclosed to the author submitting a paper and the name(s) of the author(s) will not be disclosed to the reviewers. To allow double blinded review, please submit your main manuscript and title page as separate files.
Acknowledgements. Giornale Italiano di Endodonzia requires that all sources of institutional, private and corporate financial support for the work within the manuscript must be fully acknowledged, and any potential conflicts of interest noted. Grant or contribution numbers may be acknowledged, and principal grant holders should be listed. Acknowledgments should be brief and should not include thanks to anonymous referees and editors. Under this section please specify contributors to the article other than the authors accredited. Please also include specifications of the source of funding for the study.

References

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

References in the References section must be prepared as follows:

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

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

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

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

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

Books and other monographs

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

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

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

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

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

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