

Comparison of the Push-out Bond Strength of MTA and a Bio-ceramic Repair Material at the Furcal Area after Final Irrigation with 17% Ethylenediaminetetraacetic Acid (EDTA), and 20% Citric Acid

Segu Venkata Akhil Sai Yashwanth*, Sampathi Naga Lakshmi Reddy, Nagireddy Upendra Natha Reddy, Eragam Reddy Sri Satyavathi, Shabharish Shyam Kumar Medum, Eddula Sujayeendranatha Reddy

Department of Conservative Dentistry and Endodontics, G.Pulla Reddy Dental College and Hospital, Kurnool, Andhra Pradesh, India.

*Corresponding author:

Segu Venkata Akhil Sai Yashwanth, Postgraduate Student, Department of Conservative Dentistry and Endodontics, G.Pulla Reddy Dental College and Hospital, Kurnool, Andhra Pradesh, India.
Email: 99akhilyashwanth@gmail.com

Article History

Received: 5th January 2026
Accepted: 22nd March 2026
Published: 28th March 2026

Abstract

Background: Perforations are serious endodontic complications that require immediate repair for a successful treatment outcome. The materials used for the repair, along with the irrigants employed, play a significant role in determining the bond strength at the dentin interface. The choice of material is therefore critical for the long-term durability of the treatment.

Aim: To compare the push-out bond strength of MTA and a bioceramic repair material in furcation of mandibular molars after final irrigation with 17% Ethylenediaminetetraacetic Acid (EDTA), 20% citric acid.

Materials and methods: Forty extracted mandibular molars with standardized furcation perforations were divided into two material groups: MTA and Bio C Repair (n=20 each). Both groups were further subdivided by final irrigation: 17% EDTA and 20% citric acid (n = 10 per subgroup). After obturation and perforation repair, samples were stored for 24 hours at 100% humidity and 37°C to allow the material to set. Push-out bond strength (MPa) was measured using a universal testing machine. Data were analyzed using the Kruskal-Wallis test and Dunn's multiple comparison test with Bonferroni correction.

Results: Bio C repair irrigated with 20% citric acid exhibited significantly higher push-out bond strength than all other subgroups. Overall, Bio C Repair showed greater push-out bond strength than MTA (P<0.05).

Conclusion: The newer putty consistency material showed better bond strength compared to conventional MTA, and its mechanical properties were significantly influenced by the type of irrigant used during bio-mechanical preparation.

Keywords: Bio C Repair, Citric Acid, EDTA, MTA, Push-out bond strength.

Cite this article as: Akhil Sai Yashwanth SV, Naga Lakshmi Reddy S, Upendra Natha Reddy N, Sri Satyavathi ER, Medum SSK, Sujayeendranatha Reddy E. Comparison of the Push-out Bond Strength of MTA and a Bio-ceramic Repair Material at the Furcal Area after Final Irrigation with 17% Ethylenediaminetetraacetic Acid (EDTA), and 20% Citric Acid. *Int J Dent Mater.* 2026;8(1):10-15.

1. Introduction

The success of endodontic therapy depends on thorough chemo-mechanical preparation of the root canal system, and three-dimensional obturation that ensures complete sealing of the canal spaces previously occupied by canal

contents. Procedural accidents that occur during endodontic treatment, like perforation, unfavourably affect the prognosis of the treatment [1]. Furcal perforation is an iatrogenic or pathologic communication between the pulp

chamber floor and the periodontal tissues, which can compromise the prognosis of the endodontic therapy [2]. Successful management of any perforation requires immediate sealing with a biocompatible material that adheres well to dentin, preventing microleakage and bacterial re-entry [3]. Many materials have been used for perforation repair over the past years, ranging from amalgam, Glass ionomer cements, and super EBA to newer materials such as MTA and other calcium silicate cements [4].

Mineral Trioxide Aggregate (MTA) has been widely used for this purpose, and is considered a gold standard repair material due to its excellent sealing ability, biocompatibility, and capacity to stimulate periradicular tissue healing. However, MTA also has drawbacks, such as a long setting time and potential discolouration of the tooth over time due to the presence of ferric oxide as one of the components [5]. To address these drawbacks, new calcium silicate-based bioceramic materials have been developed. They consist of calcium silicates, calcium phosphate, calcium hydroxide, zirconium oxide, tantalum oxide, putties, and thickeners. [4] The distribution and particle size of tricalcium silicate powders affect handling and setting properties, since smaller particles can penetrate dentin tubules, leading to quicker hydration. The putty consistency provides better handling properties of the material, and the absence of ferric oxide prevents discolouration of the tooth, thus overcoming the drawback posed by MTA [6-8].

Alongside material selection, root canal irrigation is a critical factor that can influence the outcome of perforation repair. Irrigants are used during endodontic treatment for disinfection and smear layer removal, but they can also alter dentin surface characteristics and thereby affect the adhesion of repair materials [9]. Sodium hypochlorite is the gold standard irrigant used for dissolution of necrotic debris. The drawback associated with NaOCl is its inability to dissolve the smear layer [9]. Smear layer management requires the use of chelating agents as a final rinse. The most common final rinses to remove the smear layer are 17% Ethylenediaminetetraacetic Acid (EDTA) and organic acids such as citric acid. EDTA effectively chelates calcium ions in dentin and opens dentinal tubules, facilitating the removal of the inorganic smear components. Citric acid (typically 10–20%) is another decalcifying agent that can similarly expose collagen in the dentin matrix [10-12].

Push-out bond strength testing is a common in vitro method to quantify the adhesion between a repair material and dentin. It reflects the resistance of the material to dislodgement and is considered a surrogate for sealing effectiveness and interface stability. A higher push-out bond strength indicates a stronger attachment of the material inside the perforation site, which is desirable for resisting dislodging forces such as mastication. Previous push-out studies have shown that bond strength can vary widely with different materials and dentin treatments [13].

However, no previous studies have compared the push-out bond strength of Bio C repair when used as a perforation repair material. The purpose of this study was to compare the push-out bond strength of the repair material after exposure to different irrigants. The null hypothesis of the present study was that different irrigants would not affect the push-out bond strength of perforation repair materials.

2. Materials and methods

The present study was conducted in the Department of Conservative Dentistry and Endodontics, G Pulla Reddy Dental College and Hospital, Kurnool, Andhra Pradesh, India. The study obtained ethical clearance from the institutional research committee (IEC Reference No.: GPR/23/RC/CONS?23M006/IEC). Sample size calculation was performed using a power analysis based on previously published studies with similar methodology. Considering an effect size of 0.8, a significance level (α) of 0.05, and a statistical power of 80%, the minimum required sample size was calculated to be 10 specimens per subgroup. Therefore, a total of 10 samples per subgroup were included in the present study [14]. The materials used in the study are presented in Table 1.

Table 1. Materials used in the study.

Materials	Manufacturers' details
Mineral Tri Oxide Aggregate	Angelus Odonto, Londrina, Brazil
Bioceramic repair material	Angelus Odonto, Londrina, Brazil
Stainless steel hand 10 K-file	Mani, Japan
Pro taper rotary instruments	Dentsply Maillefer, Balligues, Switzerland
Hemostatic sponge	Goodwill, Surat, India
3% NaOCl	Prime Dental, Thane, India
17% EDTA	Meta Biomed, Chungcheongbuk-do, Korea
20% Citric Acid	Prime Dental, Thane, India

2.1 Sample preparation

Forty human mandibular molars extracted due to periodontal reasons, with intact furcal regions, were collected from the Department of Oral and Maxillofacial Surgery and included in the study. All teeth were cleaned of calculus and soft tissue, and stored in 0.1% thymol solution until use to prevent desiccation. Inclusion criteria were mature mandibular first molars with divergent roots and no previous endodontic treatment, resorptive defects, or cracks. The teeth were decoronated at the cemento-enamel junction using a diamond saw under water coolant, to provide clear access to the pulp chamber floor. A total of 40 samples were made and divided into two groups, groups I and II, with 20 in each (n=20). The 20 samples from this group were further divided into two subgroups (Groups IA and IB, Groups IIA and IIB) with 10 in each (n=10) based on the type of irrigants.

2.2 Furcation perforation creation

Standardized furcation perforations were created in each molar. After conventional endodontic access, a perforation was made in the centre of the pulp chamber floor (furcation area) using a #2 Gates-Glidden drill and enlarged up to #5 Gates-Glidden drill (Mani, Japan). The Gates-Glidden drill was advanced perpendicularly through the furcation floor until it just penetrated the bifurcation region, creating a through-and-through perforation from the pulp chamber to the furcation exterior. The location and size of the perforations were kept consistent by using the same bur and approach for all specimens, ensuring a uniform cylindrical defect in dentin. Any loose dentin debris was gently flushed out with distilled water. Care was taken not to excessively enlarge or irregularly shape the perforations.

The teeth were then embedded in cylindrical cold-cure acrylic molds, such that a 3 mm space was left beneath the furcation and the acrylic. The chamber was then filled with the researcher's blood, which was collected and stored in a vial. The chamber was contaminated with blood for 3 minutes to mimic bleeding that occurs during a perforation. The chamber was flushed with saline, and a hemostatic sponge (Goodwill, Surat, India) was placed underneath the furcation using hand pluggers (GDC, India). Following this, the samples were randomly divided into two main groups based on the material used to seal the perforation and further subdivided into two subgroups based on the fine rinse chelating agents used (17% EDTA/ 20% citric acid).

(Angelus Odonto, Londrina, Brazil). 3% NaOCl (Prime Dental, Thane, India), 17% EDTA (Meta Biomed, Chungcheongbuk-do, Korea), and 20% citric acid (Prime Dental, Thane, India) were used as irrigants. The 20 samples from this group were subdivided equally into two subgroups (n=10) according to the type of irrigants. Subgroup I A includes MTA + 3%NaOCl + 17% EDTA, and Subgroup I B includes MTA + 3%NaOCl + 20% Citric acid.

In group II [n=20], the perforation was repaired with Angelus Bio-C repair (Angelus Odonto, Londrina, Brazil). Similar to the group I, 3% NaOCl, 17% EDTA, and 20% citric acid were used as irrigants. The samples were further divided equally into two subgroups according to the type of irrigants: II A: Bio C repair + 3%NaOCl + 17% EDTA, and II B: Bio C repair + 3%NaOCl + 20% Citric acid. The perforation site was repaired using the repair materials in accordance with the grouping and maintained at 37°C and 100% humidity in an incubator for 24 hours.

The working length was then established by inserting a 10K file (Mani, Japan), 1mm short of the apex, after canal patency and verified radiographically. Cleaning and shaping were done with ProTaper rotary instruments (Dentsply Maillefer, Balligues, Switzerland) until size F2 file. Canals were irrigated with 3 mL of 3% NaOCl at 1 mL/min following the protocols of biomechanical preparation. Finally, canals were irrigated with 3 mL of 17% EDTA or 20% citric acid at 1 mL/min, based on the subgroups.

2.3 Evaluation of push-out bond strength

The pushout bond strength was evaluated using a Universal testing machine (Instron, Model: 3369, Canton, MA, USA). The samples mounted in acrylic blocks were subjected to compression forces that were applied with a plunger of 1mm diameter at a crosshead speed of 1mm/min. The peak force at the time of dislodgement was measured in Newtons. To express the bond strength in megapascals (MPa), the load value recorded in N was divided by the area (mm²) of the bonded interface, which was measured using the following formula:

$$\text{Bonded area (A)} = 2\pi rh$$

where π is equal to 3.14, r is the radius of the perforation, 0.65 (perforation was standardised with a diameter of 1.3 mm), and h is the height of the perforation (calibrated using a William probe).

In Group I, the Perforation was repaired with MTA

2.4 Statistical Analysis

The obtained data were analysed using the Statistical Package for Social Sciences (SPSS) Version 26.0, IBM Corp., NY, USA. The data were analyzed for normality using the Shapiro-Wilk test. Overall group comparisons were performed using the Kruskal-Wallis test. Post-hoc pairwise comparisons were conducted using Dunn's multiple comparison test with Bonferroni correction for intergroup comparisons. The p-value less than or equal to 0.05 was considered statistically significant.

3. Results

The mean and standard deviation of push-out bond strength of various groups are presented in Table 2. Group II samples demonstrated more push-out bond strength than the Group I samples. Especially, the Bio-C repair materials irrigated with 3% NaOCl and 20% Citric acid (Group IIB) showed significantly higher push-out bond strength (9.965 ± 0.433 MPa), followed by Group IIA, Bio-C repair material irrigated with 3% NaOCl + 17% EDTA (9.214 ± 0.543 MPa). Comparatively less pushout bond strength was observed with the MTA repair material with different irrigant solutions, MTA + 3% NaOCl + 17% EDTA: 7.215 ± 0.365 MPa (Group I A), and MTA + 3% NaOCl + 20% citric acid: 7.856 ± 0.291 MPa (Group IB). In both groups, the repair materials irrigated with 3% NaOCl and 20% Citric acid exhibited more pushout bond strengths. Intergroup comparison using the Kruskal-Wallis test revealed a statistically significant difference among the four groups ($p < 0.001$).

In the post-hoc analysis, significant differences in push-out bond strength were observed between all the groups (Table 3). Group IA showed significant differences with Group IB ($p = 0.0017$), Group IIA ($p = 0.00018$), and Group IIB ($p = 0.00018$). Group IB demonstrated significant differences with Group IIA ($p = 0.00018$) and Group IIB ($p = 0.00018$). Significant differences were also observed between Group IIA and Group IIB ($p = 0.0022$).

4. Discussion

The success of perforation repair depends on the sealing ability of the repair material and the sealing integrity of the coronal restoration. The present study evaluated the effect of different irrigant regimens on the push-out bond strength of two calcium silicate-based perforation repair materials, MTA and Angelus Bio-C Repair. The results demonstrated that specimens repaired with

Bio-C Repair exhibited higher mean values than those repaired with MTA, irrespective of the chelating agent used. This suggests that the type of repair material plays a significant role in determining the outcome under the tested conditions.

Table 2. Mean push-out bond strength (MPa) of the various groups used in the study.

Groups	Mean	Standard Deviation	Significance
Group I A	7.215	0.365	
Group I B	7.856	0.291	
Group II A	9.214	0.543	
Group II B	9.965	0.433	<0.001*

*Significant difference.

Table 3. Post-hoc analysis of the push-out bond strength between the groups.

Groups	p-Value	
Group I A	Group I B	0.0017*
	Group II A	0.00018*
	Group II B	0.00018*
Group I B	Group II A	0.00018*
	Group II B	0.00018*
Group II A	Group II B	0.0022*

*Significant difference.

This study not only focused on the repair of the material but also contaminated the surface with human blood, which was lacking in many of the previous studies. This condition simulates the natural conditions where some dentin walls remain covered by blood even after cleaning and drying. Studies, including one by Akcay et al., have shown that blood contamination can affect the retention of biomaterials in simulated furcation perforations [15].

Mineral trioxide aggregate has long been considered the material of choice for perforation repair because of its biocompatibility, sealing ability [16], and capacity to induce hard tissue formation. However, its prolonged setting time and susceptibility to environmental conditions, particularly exposure to irrigants, have been reported as potential limitations. [17,18] Sodium hypochlorite, while indispensable for disinfection, may adversely influence the surface characteristics and physical properties of calcium silicate-based materials, especially during the early setting phase. The interaction of NaOCl with MTA has been shown to alter surface morphology and reduce mechanical stability, which may explain the comparatively lower values observed in the MTA subgroups.

Angelus Bio-C Repair is a newer premixed calcium silicate-based material designed to overcome some of the drawbacks associated with conventional MTA. Its ready-to-use formulation,

smaller particle size, and faster hydration reaction may contribute to improved resistance against irrigant-induced alterations. The higher mean values observed in the Bio-C Repair groups in the present study may be attributed to its enhanced physicochemical stability and reduced sensitivity to chelating agents [17]. The results of this study were consistent with a previous study comparing premixed calcium silicate cements with conventional MTA. One explanation is the smaller particle size of Bio-C Repair (~2 microns), which promotes deeper penetration into the dentinal tubules, stimulating crystal growth and increasing its micromechanical retention [18].

The better bond strength exhibited by Bio C repair material to dentin in this study may be attributed to chemical adhesion between the material and dentin. Another possible reason could be that the contact of Bio C repair with moisture and tissue fluids releases active ions that interact with the organic and inorganic matrix of the dentin, promoting the formation of an intermediate area, called the Mineral Infiltration Zone (MIZ). This area of mineral infiltration in the dentin provides an excellent biological seal, minimizing the possibility of bacterial infiltration. Additionally, the better bond strength of Bio-C repair material may also be attributed to its slight setting expansion, which enhances adaptation to dentinal walls and promotes micromechanical interlocking with dentin [19]. Furthermore, the setting expansion of this material helps prevent bacterial infiltration, which is critical for avoiding recontamination and subsequent endodontic failure [19].

Chelating agents such as EDTA and citric acid are routinely used to remove the smear layer; however, they can interact with calcium silicate-based materials by chelating calcium ions essential for hydration and setting [20]. In the present study, groups irrigated with EDTA demonstrated slightly higher mean values compared with their citric acid counterparts for both repair materials [21]. Citric acid, owing to its lower pH and stronger demineralizing effect, may exert a more pronounced erosive action, potentially interfering with the material-dentin interface and early material maturation. [22,23] The study considered the use of citric acid for better biocompatibility than EDTA, making it a potentially safer option for root canal irrigation. A study by Reis-Prado et al. has shown greater potential of citric acid compared to EDTA in the release of growth factors from dentin and in promoting apical healing [24].

The low standard deviation values across all groups indicate consistent measurements and suggest good standardization of the experimental protocol. Nevertheless, the findings of this in-vitro study should be interpreted with caution, as clinical conditions such as periodontal tissue pressure and long-term aging were not simulated. Further in-vivo and long-term studies are recommended to corroborate the present findings and to evaluate the clinical performance of Bio-C Repair under different irrigation protocols.

5. Conclusion

Based on the results of this study, it can be concluded that the type of perforation repair material and the choice of final irrigant significantly influence the push-out bond strength. Bio-C Repair exhibited superior bond strength compared to MTA, regardless of the irrigant used. Comparatively, the use of citric acid as a final irrigant showed higher bond strength values to EDTA. These findings emphasize the importance of selecting appropriate repair materials and irrigants to enhance the adhesive properties and long-term success of perforation repairs.

Conflicts of interest: The authors declared no conflicts of interest.

Financial support: None.

References

1. Tiwari N, Borkar AC, Tandale A, Nighot N, Ghare S, Maral S. Comparative evaluation of the effect of various endodontic irrigants on the push-out bond strength of EndoSequence, biodentine™, and MTA plus™ root repair materials: An in vitro study. *J Int Clin Dent Res Organ* 2019;11:9-13. https://doi.org/10.4103/jicdro.jicdro_3_19
2. Sethi S, Bhushan J, Joshi RK, Singla R, Sidhu K. Effect of different irrigants on the push-out bond strength of biodentine and TheraCal LC when used for perforation repair in simulated condition. *J Conserv Dent* 2023;26:321-5.
3. Das Neves MJ, Prado MD, de Lima CO, Ballal V, Simão RA, Campos CN. Effect of different irrigation regimens on the bond strength of Biodentine used for furcal perforation repair. *Endodontic Practice Today*. 2019;13(1):49-11.
4. Hamed SA. Repair of root canal perforation by different materials. *J Bagh Coll Dentistry*. 2011;23(Special Issue):30-35.
5. Hong ST, Bae KS, Baek SH, Kum KY, Shon WJ, Lee W. Effects of root canal irrigants on the push-out strength and hydration behavior of accelerated mineral trioxide aggregate in its early setting phase. *J Endod*. 2010;36(12):1995-9. <https://doi.org/10.1016/j.joen.2010.08.039>
6. Toubes KS, Tonelli SQ, Girelli CFM, Azevedo CGS, Thompson ACT, Nunes E, Silveira FF. Bio-C Repair - A New Bioceramic Material for Root Perforation Management: Two Case Reports. *Braz Dent J*. 2021;32(1):104-110. <https://doi.org/10.1590/0103-6440202103568>
7. Kadali N, Alla RK, Guduri V, AV R, MC SS, Raju RV. Mineral Trioxide Aggregate: An overview of composition, properties and clinical applications. *Int J Dent Mater*. 2020;2(1):11-8. <https://doi.org/10.37983/IJDM.2020.2103>

8. Kolla VB, Kalyan Satish R, Sajjan GS, Madhu Varma K, Sigadam A, Dutta GS. Apical microleakage assessment of teeth obturated with single-cone gutta-percha using two calcium silicate sealers and a resin sealer: an in vitro study. *Int J Dent Mater*. 2021;3(4):100-5. <https://doi.org/10.37983/IJDM.2021.3401>
9. Mikheikina A, Babina K, Polyakova M, Doroshina V, Zaytsev A, Novozhilova N. Smear layer removing and pulp dissolving ability of sodium hypochlorite mixed with two etidronate-containing irrigants in continuous chelation technique. *Appl Sci*. 2024;14(18):8422. <https://doi.org/10.3390/app14188422>
10. Dioguardi M, Gioia GD, Illuzzi G, Laneve E, Cocco A, Troiano G. Endodontic irrigants: Different methods to improve efficacy and related problems. *Eur J Dent*. 2018;12(3):459-466. <https://doi.org/10.4103/ejd.ejd.56.18>
11. Gade V, Gangrade A, Jogad N, Bhede L, Thakur D, Umale K. An in vitro evaluation of effect of chelating agents on the push-out bond strength of new perforation repair materials (Biodentine, BioAggregate and Retro MTA). *J Res Med Dent Sci*. 2021;9(12):102-106.
12. Shivani Shreya K, Deepthi G, Khwaja Moinuddin M, Pallavi R, Asha R, Amulya R. The effect of irrigating solutions on the hydration of tricalcium silicate cements: an in vitro study. *Int J Dent Mater* 2023;5(2):31-6. <https://doi.org/10.37983/IJDM.2023.5202>
13. Kassab P, El Hachem C, Habib M, et al. The Pushout Bond Strength of Three Calcium Silicate-based Materials in Furcal Perforation Repair and the Effect of a Novel Irrigation Solution: A Comparative In Vitro Study. *J Contemp Dent Pract* 2022;23(3):289-294. <https://doi.org/10.5005/jp-journals-10024-3309>
14. Maria Do Prado M, de Lima CO, das Neves Marques J, Ballal V, Simão RA, Campos CN. Effect of different irrigation regimens on the bond strength of Biodentine used for furcal perforation repair. *Int J Prosthodont*. 2019;32:49-59
15. Akcay H, Arslan H, Akcay M, Mese M, Sahin NN. Evaluation of the bond strength of root-end placed mineral tri oxide aggregate and Biodentine in the absence/presence of blood contamination. *Eur J Dent* 2016;10:370-375. <https://doi.org/10.4103/1305-7456.184150>
16. Al-Nazhan S, El Mansy I, Al-Nazhan N, Al-Rowais N, Al-Awad G. Outcomes of furcal perforation management using mineral trioxide aggregate and Biodentine: a systematic review. *J Appl Oral Sci*. 2022;30:e20220330. <https://doi.org/10.1590/1678-7757-2022-0330>
17. Lopez-Garcia S, Lozano A, Garcia-Bernal D, Forner L, Llena C, Guerrero Girones J, et al. Biological effects of new hydraulic materials on human periodontal ligament stem cells. *J Clin Med* 2019;8:1-13. <https://doi.org/10.3390/jcm8081216>
18. Leal F, De-Deus G, Brandão C, Luna A, Souza E, Fidel S. Similar sealability between bioceramic putty ready-to-use repair cement and white MTA. *Braz Dent J* 2013;24:362-366. <https://doi.org/10.1590/0103-6440201302051>
19. BIO-C® REPAIR Bioceramic reparative material, ready to use putty. Technical Scientific Profile. <https://angelus.ind.br/en/materialinformativo/endodontics/repair-cements/bio-c-repair/perfil-tecnico/>
20. Aushal R, Bansal R, Malhan S. A comparative evaluation of smear layer removal by using ethylenediamine tetraacetic acid, citric acid, and maleic acid as root canal irrigants: An *in vitro* scanning electron microscopic study. *J Conserv Dent*. 2020;23(1):71-78. <https://doi.org/10.4103/JCD.JCD.43.20>
21. Kandaswamy D, Venkateshbabu N. Root canal irrigants. *J Conserv Dent*. 2010;13(4):256-264. <https://doi.org/10.4103/0972-0707.73378>
22. Fortea L, Sanz-Serrano D, Luz LB, Bardini G, Mercadé M. Update on chelating agents in endodontic treatment: a systematic review. *J Clin Exp Dent*. 2024;16(4):e516-e538. <https://doi.org/10.4317/jced.60989>
23. Dayyoub G, Al-Tayyan M, Tolibah YA, Achour H. An in vitro assessment of the irrigants and irrigation protocols effect on the ProRoot MTA marginal leakage in furcal perforations. *Sci Rep*. 2025;15(1):6319. <https://doi.org/10.1038/s41598-025-90841-3>
24. dos Reis-Prado AH, Toledo PTA, Nunes GP, Ferreira PAV, Rahimnejad M, Dal-Fabbro R, et al. Citric acid conditioning as an alternative to EDTA for growth factors release and stem cell response in regenerative endodontics: a systematic review of in vitro studies. *J Endod*. 2024;50(2):129-143. <https://doi.org/10.1016/j.joen.2023.11.006>

Copyright © 2026 International Journal of Dental Materials.

This work is licensed under a Creative Commons Attribution-NonCommercial 4.0 International license

(<https://creativecommons.org/licenses/by-nc/4.0/>). Noncommercial uses of the work are permitted, provided the original work is properly cited