International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Bioceramics in Endodontics: Contemporary and Prospective Aspects

[1.] Dr. Emshal Malik, [2]. Dr. Bridhi Jalan, [3.] Dr. Heta Vaghasia, [4.] Dr. Vighnesh Mohandas, [5.] Dr.Tejaswini Shetty, [6.] Dr. Karthik Shetty, [7.] Dr. Roma Mascarenhas

[1] Post Graduate Student, Department of Conservative Dentistry and Endodontics, Manipal College of Dental Sciences Mangalore, Manipal Academy of Higher Education, Karnataka, Manipal- 576104, India, Email: emmy10.ea@gmail.com, Orcid id: 0009-0000-3749-855x
[2] Post Graduate Student, Department of Conservative Dentistry and Endodontics, Manipal College of Dental Sciences Mangalore, Manipal Academy of Higher Education, Karnataka, Manipal- 576104, India, Email: bridhi.jalan96@gmail.com , Orcid id: 0009-0006-0247-2396
[3] Post Graduate Student, Department of Conservative Dentistry and Endodontics, Manipal College of Dental Sciences Mangalore, Manipal Academy of Higher Education, Karnataka, Manipal- 576104, India, Email: hetavaghasia414@gmail.com, Orcid id: 0009-0000-3610-116x
[4] Post Graduate Student, Department of Conservative Dentistry and Endodontics, Manipal College of Dental Sciences Mangalore, Manipal Academy of Higher Education, Karnataka, Manipal- 576104, India, Email: vighneshmohandas@gmail.com, Orcid id: 0009-0005-7060-8307
[5] Post Graduate Student, Department of Conservative Dentistry and Endodontics, Manipal College of Dental Sciences Mangalore, Manipal Academy of Higher Education, Karnataka, Manipal- 576104, India, Email: shetty.tejaswini32@gmail.com, Phone:9909371676, Orcid id: 0009-0006-7763-7626
[6] Head of the Department, Department of Conservative Dentistry and Endodontics, Manipal College of Dental Sciences Mangalore, Manipal Academy of Higher Education, Karnataka, Manipal- 576104, India, Email: karthik.shetty@manipal.edu, Phone: 9900008040, Orcid id: 0000-0002-1901-4029
[7] (Corresponding author), Associate Professor, Department of Conservative Dentistry and Endodontics Manipal College of Dental Sciences Mangalore, Manipal Academy of Higher Education, Karnataka, Manipal- 576104, India, Email: roma.m@manipal.edu, Phone: 919902338318, Orcid id: https://orcid.org/0000-0003-3407-8685

ABSTRACT :

The superior biological activity and compatibility of bioceramics render them a favored option in dentistry, particularly in endodontics. The predominant bioceramic employed in endodontics is mineral trioxide aggregate (MTA). Numerous novel bioceramics demonstrated potential for endodontic therapy. This review examines bioceramics and their application in endodontic procedures, including root-end filling, root canal therapy, vital pulp therapy, apexification/regenerative endodontic treatment, perforation repair, and root defect repair. Novel bioceramics like as Biodentine, EndoSequence, and calcium-enriched formulations have exhibited promising clinical outcomes; however, further controlled studies are necessary to validate their application in endodontics. To resolve endodontic issues, bioceramics require enhancement in their biological activity, including antibacterial properties, mechanical characteristics, and diminished setting time and solubility.

Keywords: bioceramics; endodontic diseases; vital pulp therapy; root canal therapy; endodontic microsurgery; regenerative endodontic treatment

Introduction-

Advancements in the science of materials underscore the essential function of endodontic materials in the outcomes of treatment, leading to the practical adoption of calcium silicate-based materials (Bioceramics) due to their superior physicochemical and biological qualities. Bioceramics include materials such as alumina, zirconia, bioactive glass, hydroxyapatite, calcium phosphate, and mostly calcium silicate-based cements (1). They are categorised into bioinert, biologically active, and disposable types, with calcium silicate hydraulic cements (e.g., MTA, Biodentine, Endosequence) being the most commonly used in endodontic therapy.(2)

Mineral Trioxide Aggregate (MTA), launched in 1993 and permitted by the FDA by 1997, continues to be the benchmark for bioceramic applications owing to its exceptional biological compatibility, seal efficacy, and capacity to promote hydroxyapatite formation.(3) MTA's intrinsic benefits have established it as a fundamental component in endodontics, especially for root end fillings and pulp therapy; nonetheless, its disadvantages, such as prolonged setting periods, elevated costs, and the risk of tooth discolouration, have prompted the creation of novel calcium silicate-based materials.(4)

Contemporary bioceramics, such as Biodentine, Bioaggregate, Endosequence, iRoot, and calcium-enriched mixture (CEM), seek to preserve the advantages of MTA while mitigating its drawbacks—enhancing workability, minimising discolouration, decreasing setting time, removing heavy metal content, and strengthening mechanical strength.(5)

The primary benefits of bioceramics include exceptional biocompatibility, dimensional stability (they do not contract and may slightly expand for optimal sealing), intrinsic antibacterial properties due to elevated pH during setting, hydrophilicity, and the capacity to enhance mineralisation and tissue regeneration. These characteristics facilitate their efficacy in creating resilient seals, promoting healing, and functioning as dependable obturation materials. Calcium silicate-based bioceramics provide significant advantages, establishing them as an essential component of standard endodontic procedures. (6–9)

Applications of various bioceramics in Endodontics -

Recently, endodontic techniques have increasingly utilised bioceramics. Materials such as MTA, Biodentine, BioAggregate, BC Putty, and CEM are commonly utilised for retrograde obturation, management of deep caries, apexification/regenerative endodontic therapy, repair of perforation sites, and remediation of root defects. Bioceramics, available in powder-liquid and paste forms such as BioRoot RCS and BC Sealer, are commonly employed in endodontic obturations.

1. **Strategies for Managing Deep Caries**

Recently discovered active restoration materials have facilitated less aggressive and less invasive operations for damaged dental pulp.(10) Essential Pulp Therapy Alternatives, including as direct and indirect pulp capping, along with the pulpotomy, are conservative techniques aimed at preserving dental pulp life and functionality following injury. Selecting the appropriate capping material is essential, and MTA is commonly utilised and studied.(11) The AAE agreement advocates for the use of CSCs in the treatment of deep tooth decay due to their effective clinical results.(12)

MTA employed in VPT yields constant treatment outcomes and preserves pulp viability more effectively than calcium hydroxide.(13,14) BioAggregate serves as a feasible alternative to MTA for pulp capping and demonstrates excellent under laboratory conditions biological compatibility.(15) Remedial dentinal bridges can be created with BC Putty, which is also pulp tissue friendly. The clinic-histological efficacy of biodentine in vital pulp therapy surpasses that of calcium hydroxide, evidenced by reduced postoperative pain and sensitiveness, enhanced dentinal bridge formation, and diminished pulpal infection. (16)

Pulpotomy is a surgery that involves the excision of inflammatory coronal pulp to preserve the health of the radicular pulp. Pulpotomy may be classified as either full or partial based on the degree of dental pulp resection.(17) MTA in pulpotomy can produce outstanding results, supported by robust evidence.(18) Recently, pulpotomy utilising Biodentine has demonstrated excellent sealability and improved outcomes. (19) BC Putty has demonstrated superior compliance among patients for pulpotomy and may be regarded as a viable option.(20)

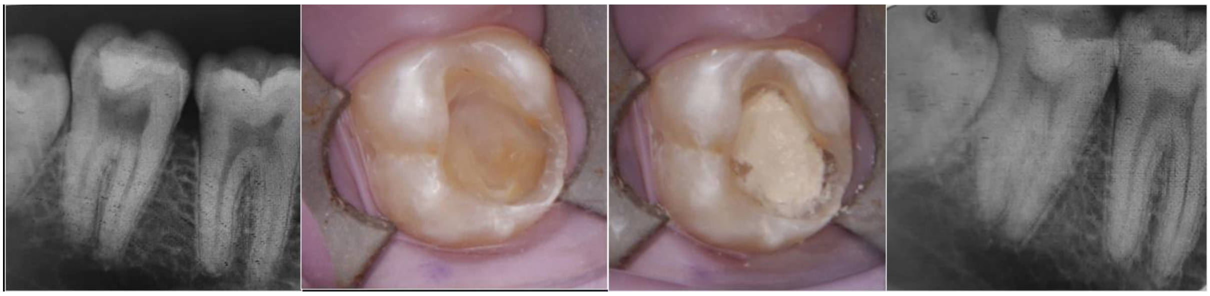

Figure 1: Clinical Procedure of Indirect Pulp Capping with MTA

2. **Endodontic Obturation**

Bioceramic root canal sealers, primarily calcium silicate-based formulations like EndoSequence BC Sealer, BioRoot RCS, and TotalFill BC, have transformed obturation techniques. These compounds exhibit exceptional biocompatibility, hydrophilicity, and stability in dimension, expanding marginally ($< 0.2\%$) upon setting and establishing a chemical link with dentin via apatite-like precipitate, thereby augmenting their sealing efficacy. (21,22) Their superior fluidity and small particle size enable the implementation of streamlined obturation protocols—particularly via hydraulic condensing or single-cone technique—where gutta-percha primarily acts as a conduit for the sealer, thereby simplifying processes and alleviating tension on the root framework. (23,24) A substantial retrospectively clinical investigation indicated a 90.9% rate of success at thirty months. with BC sealer-based obturations.(25) Despite considerations regarding retreatability—evidence indicates that sealer remnants may endure—attaining working duration and integrity during retreatment is typically feasible.(26) Calcium silicate–based sealers provide a biologically advantageous, simple to operate, and efficient replacement to conventional root canal sealers.

3. **Regenerating Endodontic Techniques**

The objective of these biologically inspired treatments is to restore the root canal system with a functioning pulp-dentin complex, primarily in young adult teeth suffering from death.(27) Calcium silicate bioceramics have a crucial role as bioactive scaffolding or hermetic barriers that facilitate stem cell migration, angiogenesis, which odontoblastic distinction, and hard-tissue development. Their hydrophilic properties, alkaline levels, and continuous release of calcium create an advantageous environment for dental pulp stem cells, while also promoting mineralised apical barrier creation and inhibiting microbial growth. Clinical treatments frequently employ clots of blood or collagen-based indigenous scaffolding in conjunction with bioceramics—such as MTA or Biodentine coronal plugs—to occlude canals and facilitate continued biological activity. Preclinical and growing clinical research indicate that functionalised scaffolds containing calcium silicate bioceramics can improve cell homing and pulp regrowth, while a full reconstruction of vascularised, innervated pulp tissue remains a desirable objective.(28) As study advancements, hybrid structures integrating bioceramics with growth factors, nanofibrous matrices, and stem cells are demonstrating potential in advancing the field from straightforward tissue repair to authentic pulp renewal, restoring perceptual and immunological functions.(29)

4. **Apical end Filling**

Apexification in immature permanent teeth has advanced considerably with the introduction of calcium silicate bioceramics, including MTA, Biodentine, and bioceramic putties, converting apical closure from a lengthy, multi-visit procedure to a streamlined, effective single-visit treatment. MTA is regarded as the "standard of excellence" for apical barriers, providing dependable hard-tissue development, superior sealing capability, and elevated clinical response rates—reaching 96% in future case studies. (30) Significant research demonstrates that complete canal obturation with MTA markedly improves resistance to fractures in juvenile teeth (31), Extensive study indicates that full canal obturation with MTA significantly enhances durability against fractures in adolescent teeth. (23) Bioceramic putties such as BC RRM and TotalFill BC Putty have exhibited encouraging clinical and radiological results, with rates of success reaching 100% in certain cases, facilitating apical repair and root development. Furthermore, CEM cement exhibits resistance to fractures and permeability efficiency comparable to MTA; however, further clinical testing is required. (2)

5. **Perforation Repair:**

The American Association of Endodontists defines root canal perforation as a physiologically or pathologically linked connection between the pulp space system and the external surface of the tooth (34). Such perforations can lead to significant gingival deterioration, encompassing inflammatory reactions, breakdown of periodontal fibres, decreased bone density, and the formation of abnormalities. They generally occur during clinical operations, such as the fabrication of access cavities or the building of post spaces, and can also happen from internal resorption (35,36).

Advancements in nanomaterials have significantly enhanced the results of perforation correction. Prior materials, such as zinc oxide eugenol (ZOE), glass ionomer cement (GIC), and composite resins, have been employed; however, their use has been limited by insufficient compliance and variable clinical results (37-41). The emergence of bioceramic materials has revolutionised perforation management due to its remarkable securing capacity, biological dependability, and regenerative potential. Biodentine demonstrates beneficial operational properties and clinical efficacy (42), in contrast, EndoSequence exhibits superior sealing properties, particularly in furcation defects (43). BioAggregate exhibits enhanced resilience to acidic environments relative to MTA (44,45).

6. **Repair of resorption (Internal and external):**

Internal root resorption is a challenging endodontic condition characterised by irregular diseased morphology and an elevated likelihood of external root perforation. Despite these constraints, the principal treatment objective remains the preservation of a functional dentition. Advancements in materials research, particularly in the development of bioceramic materials with superior biophysical and physiological properties, have significantly improved the care of these situations. Their bioinert properties, significant biocompatibility, and harmless nature render bioceramics especially suitable for mitigating resorptive inadequacies (46).

A fundamental challenge in managing internal resorption is creating a multidimensional, hermetic seal within the irregular cavity. Traditional obturation techniques often do not align with the resorptive architecture. Consequently, bioceramic materials have attained therapeutic importance due to their exceptional sealing capability and user-friendliness (47).

MTA demonstrates significant reparative ability because to its high alkalinity (pH 12.5) and inherent antibacterial properties, which promote cementogenesis and periradicular bone growth (48-50).

7. **Endodontic microsurgery:**

Endodontic microsurgery (EMS) is a recognised procedure for the conservation of teeth impacted by intricate periapical diseases. The integrity of the root-end filling is a crucial factor in surgical success, since it is vital for establishing a lasting apical seal, thus reducing microleakage and the likelihood of reinfection (2). In contrast, peri-radicular cauterisation performed with no root-end filling fails to address the underlying cause of periapical leaks and offers negligible lasting advantages. Extensive clinical evidence underscores the substantial influence of root-end filling materials on the total efficacy of surgical endodontic procedures (51). The standard scopic strategy involves 3 mm of apical resection followed by 3 mm of retro prep of the cavity, an essential step in both microsurgical and intentional replantation methods (52,53) Mineral trioxide aggregate (MTA) remains the preferred material for retrograde filling owing to its excellent sealing properties, biologic compatibility, and sustained clinical efficacy. Numerous long-term investigations have evidenced elevated recovery percentages with MTA: Çalışkan et al. observed a healing rate of 80% over a 2–6 year monitoring including 90 anterior teeth (54); von Arx et al. recorded an 81.5% healing rate in 119 teeth over a 10-year follow-up period(55,56).

Conclusion:

Bioceramics are increasingly essential in endodontic routine, providing biodegradable and bioactive options that tackle various issues related to endodontic procedures. Although materials such as MTA previously established the benchmark, continuous innovations have sought to address its limitations and improve overall material efficacy. Currently, bioceramics are extensively utilised in endodontics and restorative dentistry. Notwithstanding their advantageous biological and mechanical characteristics, existing bioceramic materials possess certain limitations. Frequently mentioned problems encompass tooth discolouration, extended setting durations, challenges in handling, and compatibility issues. Furthermore, a significant portion of the current research relies on in vitro investigations, which may not accurately represent clinical efficacy, and literature reviews frequently exhibit overgeneralisation. These issues underscore the necessity for ongoing advancement and clinical verification of bioceramic materials. Ultimately, remaining updated about the newest breakthroughs is crucial for picking the most suitable material for each clinical circumstance and optimising treatment outcome.

REFERENCES:

1. Surya Raghavendra S, Jadhav GR, Gathani KM, Kotadia P. BIOCERAMICS IN ENDODONTICS – A REVIEW. J Istanb Univ Fac Dent. 2017 Nov 17;51(0).
2. Dong X, Xu X. Bioceramics in Endodontics: Updates and Future Perspectives. Vol. 10, Bioengineering. MDPI; 2023.

3. Parirokh M, Torabinejad M. Mineral Trioxide Aggregate: A Comprehensive Literature Review-Part I: Chemical, Physical, and Antibacterial Properties. Vol. 36, Journal of Endodontics. 2010. p. 16–27.
4. Parirokh M, Torabinejad M. Mineral Trioxide Aggregate: A Comprehensive Literature Review-Part III: Clinical Applications, Drawbacks, and Mechanism of Action. Vol. 36, Journal of Endodontics. 2010. p. 400–13.
5. Zafar K, Jamal S, Ghafoor R. Bio-active cements-mineral trioxide aggregate based calcium silicate materials: A narrative review. Vol. 70, Journal of the Pakistan Medical Association. Pakistan Medical Association; 2020. p. 497–504.
6. Lim M, Jung C, Shin DH, Cho Y bum, Song M. Calcium silicate-based root canal sealers: a literature review. Restor Dent Endod. 2020;45(3).
7. Donnermeyer D, Bürklein S, Dammaschke T, Schäfer E. Endodontic sealers based on calcium silicates: a systematic review. Vol. 107, Odontology. Springer Tokyo; 2019. p. 421–36.
8. Al-Haddad A, Aziz ZACA. Bioceramic-Based Root Canal Sealers: A Review. Vol. 2016, International Journal of Biomaterials. Hindawi Limited; 2016.
9. Aminoshariae A, Primus C, Kulild JC. Tricalcium silicate cement sealers: Do the potential benefits of bioactivity justify the drawbacks? Vol. 153, Journal of the American Dental Association. American Dental Association; 2022. p. 750–60.
10. Duncan HF. Present status and future directions—Vital pulp treatment and pulp preservation strategies. Vol. 55, International Endodontic Journal. John Wiley and Sons Inc; 2022. p. 497–511.
11. Tong HJ, Seremidi K, Stratigaki E, Kloukos D, Duggal M, Gizani S. Deep dentine caries management of immature permanent posterior teeth with vital pulp: A systematic review and meta-analysis. Vol. 124, Journal of Dentistry. Elsevier Ltd; 2022.
12. AAE Position Statement on Vital Pulp Therapy.
13. Bjørndal L, Simon S, Tomson PL, Duncan HF. Management of deep caries and the exposed pulp. Vol. 52, International Endodontic Journal. Blackwell Publishing Ltd; 2019. p. 949–73.
14. Matsuura T, Ziauddin SM, Kawata-Matsuura VKS, Sugimoto K, Yamada S, Yoshimura A. Long-term clinical and radiographic evaluation of the effectiveness of direct pulp capping materials: A meta-analysis. Vol. 40, Dental Materials Journal. Japanese Society for Dental Materials and Devices; 2021. p. 1–7.
15. Islam R, Islam MRR, Tanaka T, Alam MK, Ahmed HMA, Sano H. Direct pulp capping procedures – Evidence and practice. Vol. 59, Japanese Dental Science Review. Elsevier Ltd; 2023. p. 48–61.
16. Abdul M, Murali N, Rai P, Mirza M, Salim S, Aparna M, et al. Clinico-histological evaluation of dentino-pulpal complex of direct pulp capping agents: A clinical study. J Pharm Bioallied Sci. 2021 Jun 1;13(5):S194–8.
17. Sadaf D. Success of Coronal Pulpotomy in Permanent Teeth with Irreversible Pulpitis: An Evidence-based Review. Cureus. 2020 Jan 23;
18. Li Y, Sui B, Dahl C, Bergeron B, Shipman P, Niu L, et al. Pulpotomy for carious pulp exposures in permanent teeth: A systematic review and meta-analysis. Vol. 84, Journal of Dentistry. Elsevier Ltd; 2019. p. 1–8.
19. Jiménez-Martín C, Martín-González J, Crespo-Gallardo I, Montero-Miralles P, Cabanillas-Balsera D, Segura-Egea JJ. Elective full pulpotomy in mature permanent teeth diagnosed with symptomatic irreversible pulpitis: a two years retrospective study. Clin Oral Investig. 2024 Aug 1;28(8).
20. Guan X, Zhou Y, Yang Q, Zhu T, Chen X, Deng S, et al. Vital pulp therapy in permanent teeth with irreversible pulpitis caused by caries: A prospective cohort study. J Pers Med. 2021 Nov 1;11(11).
21. Alkahtany SM, AlHussain AA, AlMthen HA, AlDokhi HD, Bukhary SM, Almohaimede AA, et al. Obturation quality of bioceramic sealers with different obturation techniques: a micro-CT evaluation. Sci Rep. 2024 Dec 1;14(1).
22. Wang Z, Shen Y, Haapasalo M. Antimicrobial and antibiofilm properties of bioceramic materials in endodontics. Vol. 14, Materials. MDPI; 2021.
23. Wang X, Xiao Y, Song W, Ye L, Yang C, Xing Y, et al. Clinical application of calcium silicate-based bioceramics in endodontics. Vol. 21, Journal of Translational Medicine. BioMed Central Ltd; 2023.
24. Penha Da Silva PJ, Marceliano-Alves MF, Provenzano JC, Dellazari RLA, Gonçalves LS, Alves FRF. Quality of Root Canal Filling Using a Bioceramic Sealer in Oval Canals: A Three-Dimensional Analysis. Eur J Dent. 2021 Jul 1;15(3):475–80.
25. Chybowski EA, Glickman GN, Patel Y, Fleury A, Solomon E, He J. Clinical Outcome of Non-Surgical Root Canal Treatment Using a Single-cone Technique with Endosequence Bioceramic Sealer: A Retrospective Analysis. J Endod. 2018 Jun 1;44(6):941–5.
26. Kakoura DDS F, Pantelidou DDS, PhD O. Retreatment Efficacy of Endodontic Bioceramic Sealers: A Review of the Literature. Odovtos - International Journal of Dental Sciences. 2018 May 21;20(2):39–50.
27. Wei X, Yang M, Yue L, Huang D, Zhou X, Wang X, et al. Expert consensus on regenerative endodontic procedures. Vol. 14, International Journal of Oral Science. Springer Nature; 2022.
28. De la cruz-Rocha ER, Parada-Sanchez MT, Arboleda-Toro D, Cañas-Gutierrez AI. Pulp Regeneration in Necrotic Teeth Based on Functionalized Scaffolds: a Review of Clinical and Experimental Strategies. Vol. 12, Current Oral Health Reports. Springer Science and Business Media B.V.; 2025.
29. Farjaminejad R, Farjaminejad S, Garcia-Godoy F. Regenerative Endodontic Therapies: Harnessing Stem Cells, Scaffolds, and Growth Factors. Vol. 17, Polymers. Multidisciplinary Digital Publishing Institute (MDPI); 2025.
30. Rafter M. Apexification: A review. Vol. 21, Dental Traumatology. 2005. p. 1–8.
31. Darak P, Likhitkar M, Goenka S, Kumar A, Madale P, Kelode A. Comparative evaluation of fracture resistance of simulated immature teeth and its effect on single visit apexification versus complete obturation using MTA and biodentine. J Family Med Prim Care. 2020;9(4):2011.

32. Zanjad SR, Justin RM, Patil PN, Sarda AS, Srivastava HM, Darade LD. Comparison of fracture resistance of simulated immature teeth using four different commercially available apexification materials - An in vitro study. Indian J Dent Res. 2023 Jan 1;34(1):75–9.
33. Anjum FS, Brusevold IJ, Wigen TI. Prognosis of non-vital incisors after apexification using bioceramics: a retrospective study. European Archives of Paediatric Dentistry. 2024 Oct 1;25(5):637–44.
34. Clauder T. Present status and future directions – Managing perforations. Vol. 55, International Endodontic Journal. John Wiley and Sons Inc; 2022. p. 872–91.
35. Alshehri MM, Alhawsawi BF, Alghamdi A, Aldobaikhi SO, Alanazi MH, Alahmad FA. The Management of Root Perforation: A Review of the Literature. Cureus. 2024 Oct 24;
36. KVINNSLAND I, OSWALD RJ, HALSE A, GRØNNINGSÆTER AG. A clinical and roentgenological study of 55 cases of root perforation. Int Endod J. 1989;22(2):75–84.
37. Kakani AK, Veeramachaneni C, Majeti C, Tummala M, Khiyani L. A review on perforation repair materials. Vol. 9, Journal of Clinical and Diagnostic Research. Journal of Clinical and Diagnostic Research; 2015. p. ZE09-ZE13.
38. Ree M, Schwartz R. Management of perforations: Four cases from two private practices with medium- to long-term recalls. J Endod. 2012;38(10):1422–7.
39. Torabinejad M, Parirokh M, Dummer PMH. Mineral trioxide aggregate and other bioactive endodontic cements: an updated overview – part II: other clinical applications and complications. Vol. 51, International Endodontic Journal. Blackwell Publishing Ltd; 2018. p. 284–317.
40. Gorni FG, Andreano A, Ambrogi F, Brambilla E, Gagliani M. Patient and Clinical Characteristics Associated with Primary Healing of Iatrogenic Perforations after Root Canal Treatment: Results of a Long-term Italian Study. J Endod. 2016 Feb 1;42(2):211–5.
41. Krupp C, Bargholz C, Brüsehaber M, Hülsmann M. Treatment outcome after repair of root perforations with mineral trioxide aggregate: A retrospective evaluation of 90 teeth. J Endod. 2013 Nov;39(11):1364–8.
42. Suryawanshi T, Chandak M, Patel A, Ikhar A, Sedani S, Jidewar NP, et al. Management of a Case of a Large Perforation Repair With Biodentine. Cureus. 2024 Jun 10;
43. Jeevani E, Jayaprakash T, Bolla N, Vemuri S, Sunil CR, Kalluru RS. Evaluation of sealing ability of MM-MTA, Endosequence, and biodentine as furcation repair materials: UV spectrophotometric analysis. Journal of Conservative Dentistry. 2014;17(4):340–3.
44. Abdel A, Hashem R. The Push-Out Bond Strength of Different Furcation Perforation Repair Materials: A comparative study [Internet]. Available from: https://www.researchgate.net/publication/260219493
45. Asgary S. Furcal perforation repair using calcium enriched mixture cement. Journal of Conservative Dentistry. 2010;13(3):156.
46. Riyahi AM. Bioceramics utilization for the repair of internal resorption of the root: A case report. World J Clin Cases. 2022 Oct 26;10(30):11185–9.
47. Bhopatkar J, Ikhar A, Nikhade P, Chandak M, Agrawal P. Emerging Paradigms in Internal Root Resorption Management: Harnessing the Power of Bioceramics. Cureus. 2023 Sep 13;
48. Holland R, Bisco Ferreira L, de Souza V, Otoboni Filho JA, Murata SS, Dezan E. Reaction of the Lateral Periodontium of Dogs' Teeth to Contaminated and Noncontaminated Perforations Filled with Mineral Trioxide Aggregate. J Endod. 2007 Oct;33(10):1192–7.
49. Howait M, Shaker M, Aljuhani H, Almohnna M. External Cervical Resorption: A Case Report and Brief Review of the Literature, and Treatment Algorithms. Journal of Contemporary Dental Practice. 2021 Mar 1;22(3):298–303.
50. Dudeja C, Taneja S, Kumari M, Singh N. An in vitro comparison of effect on fracture strength, pH and calcium ion diffusion from various biomimetic materials when used for repair of simulated root resorption defects. Journal of Conservative Dentistry. 2015 Jul 1;18(4):279–83.
51. Chao YC, Chen PH, Su WS, Yeh HW, Su CC, Wu YC, et al. Effectiveness of different root-end filling materials in modern surgical endodontic treatment: A systematic review and network meta-analysis. J Dent Sci. 2022 Oct 1;17(4):1731–43.
52. Floratos S, Kim S. Modern Endodontic Microsurgery Concepts: A Clinical Update. Vol. 61, Dental Clinics of North America. W.B. Saunders; 2017. p. 81–91.
53. Jadun S, Monaghan L, Darcey J. Endodontic microsurgery. Part two: armamentarium and technique. Br Dent J. 2019 Jul 1;227(2):101–11.
54. Çalişkan MK, Tekin U, Kaval ME, Solmaz MC. The outcome of apical microsurgery using MTA as the root-end filling material: 2- to 6-year follow-up study. Int Endod J. 2016 Mar 1;49(3):245–54.
55. von Arx T, Jensen SS, Janner SFM, Hänni S, Bornstein MM. A 10-year Follow-up Study of 119 Teeth Treated with Apical Surgery and Root-end Filling with Mineral Trioxide Aggregate. J Endod. 2019 Apr 1;45(4):394–401.
56. Kim D, Lee H, Chung M, Kim S, Song M, Kim E. Effects of fast- and slow-setting calcium silicate–based root-end filling materials on the outcome of endodontic microsurgery: a retrospective study up to 6 years. Clin Oral Investig. 2020 Jan 1;24(1):247–55.