ORIGINAL RESEARCH PAPER
Volume - 11 | Issue - 08 | August - 2022 | PRINT ISSN No. 2277 - 8179 | DOI : 10.36106/ijsr
INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH

ENDOSEQUENCE ROOT REPAIR MATERIAL (ERRM): A LITERATURE REVIEW

Dentistry

Dr. Shrimahalakshmi* Postgraduate, Department of Pedodontics and Preventive Dentistry, Sri Siddhartha Dental College and Hospital, Sri Siddhartha Academy of Higher Education (SSAHE), Tumkur-India - 572107 *Corresponding Author

Dr. Nagalakshmi Chowdhary Head of the department and Professor, Department of Pedodontics and Preventive Dentistry, Sri Siddhartha Dental College and Hospital, Sri Siddhartha Academy of Higher Education (SSAHE), Tumkur, India - 572107

Dr. Veena Shivanna Associate Professor, Department of Pedodontics and Preventive Dentistry, Sri Siddhartha Dental College and Hospital, Sri Siddhartha Academy of Higher Education (SSAHE), Tumkur, India - 572107

ABSTRACT

Bioceramics are biocompatible ceramic material specifically developed to be used in medical and dental fields to repair and reconstruct diseased or damaged part. Since 1990's MTA is a widely used bioceramics in dentistry. ERRM, a new bioceramic endodontic material available in pre-mixed syringes, is demonstrated to be an effective material for various endodontic treatments with similar properties to MTA. It has good antimicrobial properties with superior osteo/ odonto induction potential. ERRM and iRoot can be effectively used as root repair material in various procedures such as perforation repair, furcation repair, retrograde filling material, vital pulp therapies (pulp capping, pulpotomy), as well as in regenerative procedures. Apart from this ERRM also promotes root formation hence, can be used in regenerative procedures (apexogenesis and apexification). This review of literature is focused on the properties and clinical applications of the new bioceramic material, Endosequence Root Repair Material (ERRM).

KEYWORDS

Endosequence Root Repair Material (ERRM), iRoot BP, regeneration, endodontics, bioceramics, root repair material.

INTRODUCTION:

Regenerative endodontics, a biological procedure, carried out in immature permanent teeth with trauma or deep dentinal caries with or without pulpal exposure, in order to replace the damaged tissue with healthy tissues along with continued root development with apical foramen closure. Materials used for regenerative procedures should have the capability of inducing the mesenchymal stem cells to differentiate into the desired cell type and produce the desired effect.[1] Bioceramics are ceramic compounds, specifically designed to be used in regenerative procedures. Its superior properties like excellent biocompatibility, anti-bacterial properties, ability to induce a regenerative response in an organism makes it an suitable material for regenerative dentistry. They are homogenous, inorganic, non-metallic material that includes alumina and zirconia, bioactive glass, glass ceramics, coatings and composites, hydroxyapatite, and resorbable calcium phosphates in dentistry for various procedures like root resorptions, perforations, retrograde fillings, pulpotomy, apexification. There are numerous bioceramics available in the market- MTA, BioAggregate, Biodentin, Endosequence Root Repair material (ERRM). MTA is the gold standard bioceramic material used since decades. Also, various authors in the literature suggested ERRM as an alternative material for regenerative procedures.[2,3,4] This literature review presents an overall properties and applications of ERRM/ iRBP in dentistry.

Endosequence Root Repair Material:

ERRM, a new bioceramic aluminium free material, introduced in recent decades as a modified version of MTA, to improve its handling properties and clinical outcome. ERRM holds an excellent alternative for MTA because of its superior anti-microbial efficacy, biocompatibility, and improved physical properties.[5]

No tooth discoloration has observed using this material because it contains zirconium oxide for its radiolucency, not bismuth oxide as in MTA. ERRM is a ready-to-use white hydraulic premixed putty material which is a totally a synthetic calcium-silicate-based cement. It is also available as iRoot SP, iRoot FS (iRFS), iRoot BP, and iRoot BP Plus (iRBP).[4]

Composition and uses ERRM:

According to the instruction manual, it is composed of tricalcium silicate, zirconium oxide, tantalum pentoxide, dicalcium silicate, calcium sulphate, calcium phosphate monobasic, and filler agents. According to the manufacturer, the application of ERRM includes root-end fillings, apexification, pulpotomy, and indirect or direct pulp capping.[5]

Setting Time:

It is commercially available in premixed syringes which is carried to the desired tooth using a sterile plastic instrument. ERRM is a hydrophilic material and requires the presence of water to set and harden. The setting reaction is initiated instantly as the cement comes in contact with water/ moisture that eliminates the need for complete isolation which is difficult to achieve in children. iRBP sets in two hours[6] whereas ERRM reaches its initial set at 61.8 ± 2.5 minutes and final set at 208 ± 10.0 minutes. iRFS has the fast-setting time reaches its initial set at 18.3 ± 2.6 minutes and final set within 1 hour.[7]

Properties of ERRM:

1.Tissue Regeneration:

Dental pulp is a highly vascular loose connective tissue, consists of predominant odontoblasts and undifferentiated mesenchymal cells. In response to an injury, the undifferentiated mesenchymal cells differentiate into odontoblasts-like cells and forms reparative dentin near the injured site.[8] The alkaline phosphatase activity represents an early marker for odonto/ osteogenic differentiation as it plays an important role in the formation hydroxyapatite crystals. The association of alkaline phosphatase (ALP) activity level with dentin mineralization is well documented in the literature. iRBP is shown to have the highest ALP activity which is constantly upregulated throughout the culture period (1 – 7 days) with its highest activity (CCK-8 assay) during days 3, 5, 7 than MTA. This represents the highest mineralization of iRBP to MTA.[9] SEM and CLSM showed excellent adhesion and attachment of different human cells over the surface of set cement similar to MTA which represents the greater biocompatibility of iRBP.

The odonto/ osteogenic potential of iRBP was found to be similar to MTA. iRBP triggers the odonto/ osteogenic differentiation of BMMSC (Bone Marrow Mesenchymal Stem Cells) by promoting gene expression and protein levels of dentin sialo phosphoprotein (DSPP), osterix (OSX), osteopontin (OPN), and runt-related transcription factor-2 (RUNX-2). It induces BMMSC via MAPK and autophagy pathways.[8] The iRBP induced the mRNA expression of specific odontoblastic markers (OC, DSP, DMP-1).[9]

2. Cytotoxicity:

ERRM contains zirconium oxide and iRBP contains tantalum oxide

for its radioopacity instead of barium oxide as in MTA to eliminate the toxic effect of barium oxide. However, the cytotoxic property of iRBP was found to be similar to MTA.[10]

3. Effect On Blood Exposure:
The exposure of the material to blood is inevitable when used as a medicament in certain procedures like direct pulp capping, pulpotomy, apexogenesis, perforation repair. Studies have proved the negative effects of dental material on blood exposure. This is because, the albumin, the plasma protein and other constituents of blood occludes the dentinal tubules and adversely affects the hydroxy apatite formation. With no exception ERRM required more than 48 hours to set in the presence of blood.[11] However, the push bond strength of ERRM decreased immediately after its exposure to blood but, significantly increased after 72 hours.[12]

4. Anti-microbial Efficacy:
The antimicrobial effect of iRBP was found to be significantly higher compared to MTA-HP (Mineral Trioxide Aggregate- High Plasticity). iRBP inhibits the growth of *Enterococcus faecalis,* the most prevalent micro-organism responsible for both primary and secondary infection of teeth. In addition, it also inhibits gram-positive cocci- *Staphylococcus aureus, Streptococcus mutans,* and superior antimicrobial activity against *Enterococcus faecium, Peptostreptococcus anaerobius*, and *Candida albicans* than MTA-HP. It showed no antibacterial effect against *Porphyromonas gingivalis* and *Actinomyces israelii*.[13] Another study concluded that the iRBP has a similar anti-microbial effect as MTA against *Enterococcus faecalis* and *Candida albicans* but it does not possess an inhibitory effect on *Enterococcus faecalis.*[14] ERRM is proved to be effective against ten strains of *Enterococcus faecalis*.[15]

5. pH:
iRoot BP is strongly alkaline in nature with higher initial pH measurements at 5 minutes and 60 minutes (12.1 ± 0.14 and 11.9 ± 0.25). At this higher alkaline pH, the hydroxyl ions affect the cell membrane and the enzymatic activity of the micro-organisms.[13] However, the iRBP releases markedly higher concentrations of calcium and silica in acidic environment (pH 5.4) than in physiologic environment (pH 7.4).[16] An acidic environment reduced the surface microhardness of ERRM.

6. Porosity:
Porosities formed in the endodontic material space for bacterial growth resulting in microleakage thereby failure of root canal treatment in permanent teeth. Operator-related factors such as the type of mixing and physical properties of the material are reasons for porous formation. The premixed ready to use root canal sealer ERRM has significantly lesser porosity than grey-MTA and white-MTA.[7] iRBP demonstrated a similar degree of porosity as conventional MTA.[17]

7. Sealing Ability:
Sealing property of ERRM is enhanced over time, featuring the least leakage on day10 and 28. Whereas the ERRM showed similar dye penetration as MTA when used to furcation repair suggesting that it could be a desirable alternative for MTA in root-end filling material.[18,19] However, the ERRM putty showed good marginal adaptation to the root canal walls similar to MTA than ERRM paste.[20]

8. Dentinal Tubule Penetration Of Root Canal Sealers:
A hermetic seal prevents reinfection in the root canals after treatment which can be achieved by the penetration and interaction of the sealer in dentinal tubules. iRoot SP displayed a greater area of penetration than MTA. Extremely smaller particles with less than two microns in size and high viscosity of iRoot SP attributes to its penetration into the dentinal tubules. Further, iRoot SP undergoes 0.2% expansion while setting.[21]

9. Microhardness:
ERRM, the set material exhibited lowest microhardness on day one with a gradual increase over 28 days but reached similar to MTA on 4th day.[7]

10.Fracture Strength:
The fracture strength of ERRM is similar to MTA-Plus and MTA Angelus. ERRM showed better fracture resistance when placed in the coronal one-third[22,23] (as in regenerative endodontic procedures) or in the apical one-third[24] (as in retrograde filling material). The mean fracture strength value for ERRM is 17.65 ± 4.28 MPa.[23]

11. Compressive Strength:
The compressive strength is significantly higher than MTA in ERRM on 7th day (107.4 ± 31.1 MPa) and 28th day (176.6 ± 22.0 MPa). The strength was reduced after saline contact (40-45 MPa) at 7 days. No significant differences were found between grey-MTA, white-MTA and iRFS.[7]

12. Push Bond Strength:
A tooth repair material encounters dislocation forces such as condensation forces, mastication forces. Shortly after perforation repair, the material might dislodged from the tooth while mastication because of the longer setting time. In general, ERRM proved to have superior push bond strength at 2 months than at 1 week.[25] Exposure of blood has positive effect on push bond strength.[26] ERRM exhibited lower push bond strength when used as a root canal sealer for placing the fiber post.[27]

13. ERRM with 2% TAP incorporation:
Triple Antibiotic Paste (TAP), known for its anti-microbial efficacy, is widely used in lesion sterilization and tissue repair. The most commonly used TAP is the combination of metronidazole, ciprofloxacin, and doxycycline/ minocycline. Doxycycline/ minocycline tends to react with the available free calcium ions and forms chelates thus, compromising the effectiveness of apical plugs formed by ERRM. Thibodeau B and Trope M suggested cefaclor as an alternative for doxycycline.[28] ERRM incorporated with 2% triple antibiotic paste (ciprofloxacin, metronidazole, and cefaclor) demonstrated the highest calcium ion release from the apical plug than ERRM alone.[29]

Clinical Application In Dentistry:

1. Pulp capping/ Pulpotomy: (tertiary dentin formation)
An ideal material for pulp therapy must have biocompatibility, anti-microbial property and it should heal the pulpal wound by facilitating reparative dentin formation. iRBP enhances reparative dentin formation. iRBP has the ability to induce the formation of reparative dentin when used as a pulpotomy or direct pulp capping medicament. iRBP as an indirect pulp capping effectively remineralizes the affected dentin in 4 weeks after the partial/complete excavation of infected dentin.[30,31,32] The effect of iRBP as a pulp capping and pulpotomy material was investigated wistar rats (in-vivo). iRBP enhanced the proliferation of human dental pulp cells in-vitro.[31]

iRBP as a direct pulp capping agent, induced reparative hard dentin formation immediately below the exposed area in all the specimens on the fourth-week observation. Whereas in the MTA group only hard tissue formation was observed only in three-quarters of the specimens. The newly formed reparative dentin in the iRBP group was similar to primary dentin with dentinal tubule-like structures coupled with polarized odontoblasts like cells aligned along with the layer.[31] Micro CT analysis of tertiary dentin demonstrated superior compactness of dentinal tubules. Besides, the structure of tertiary dentin demonstrated with 3-D micro-CT analysis and histological evaluation showed homogenous dentin without defects.[32] Moreover, the adjacent pulp tissue appeared to be normal without inflammatory cells.[31]

As a pulpotomy medicament, the iRBP resulted in the formation of a layer of hard tissue in the root canal at one-week observation and a thick layer of dentin bridge, in the fourth-week observational period, that completely sealed the canal orifice with polarizing odontoblasts like cells immediately below the dentin bridge.[31]

2. Partial Pulpotomy:
An ex-vivo study conducted by Azimi et al[33] demonstrated pulp inflammation, calcific bridge formation, and dentin bridge appearance using iRBP and ProRoot MTA was similar. The calcific bridge was evaluated under microscope on day 42 that revealed a layer of flat cells behind the calcific bridge. Complete calcific bridge formation was seen in 58% of specimens and incomplete bridge formation in 42% of specimens. The calcific bridge was permeable with tubular (25%), and atubular (67%) appearance. Tunnel defect was observed in 8% of specimens. Investigation of the cells in the inflammatory infiltration showed dominant mononuclear white blood cells with a complete absence of poly morpho nuclear cells. However, partial pulpotomy using iRBP was more sensitive to cold.[33]

3. Apexogenesis:

The thickness of calcific bridge revealed a significantly thinner calcific bridge in iRBP than in CaOH. The dentin wall thickness and the root length were similar to the Calcium Hydroxide as well as when compared with the adjacent normal teeth. The survival rate of partial pulpotomy using iRBP was 90.4% at the end of 24 months.[34]

iRBP pulpotomy is a suitable alternative for calcium hydroxide pulpotomy to induce root formation in traumatized young permanent teeth with complicated fractures. iRBP exhibited a 100% of clinical and 99% of radiographic success rate. Radiographically, dentin bridge formation was appreciated in 92.3% of cases.[35] Even though, the duration for complete root formation and the thickness of dentin bridge was not assessed in this study, other studies have proven the regenerative effect of iRBP.

4. Maturogenesis:

The hydraulic calcium silicate cements induce apatite formation after interacting with physiologic phosphate ions.[25,36,37] iRBP is an excellent regenerative material that can induce root formation even in teeth undergoing apexification procedure. This was accidentally found and first reported by Nagarajan S et al.[38] Maturogenesis with the closure of apical foramen was observed in a non-vital immature mandibular premolar treated using iRBP. iRBP apexification was performed in mandibular premolar (45) which presented with a developmental anomaly, dens evaginatus. In the follow-up visit, surprisingly the radiographic evaluation revealed a continuation of root development beyond the apexification level with normal periodontal ligament and lamina dura, at 6-month follow-up. iRBP holds a promising future for regenerative procedures.[38] This provides strong evidence of regenerative property of the material. It could be hypothesized that when the material contacts the mesenchymal cells, it induces them to differentiate into odontoblasts like cells.

5. Pulpotomy In Deciduous Dentition:

iRBP as a pulpotomy medicament for deciduous teeth showed a success rate of 92.5% with complete calcified dentin bridge formation within one year. iRBP possesses an additional advantage of no tooth discoloration in treated teeth. The time taken for the procedure was significantly lesser than MTA.[39]

6. Root End Filling Material:

There is a direct contact existing between the root repair material and the periapical tissue. The primary aim of a root canal repair procedure is sealing of infected/damaged root canals permanently thereby, promoting healing of root canals and surrounding periapical tissues. Hence, the material must have an excellent sealing ability, radioopacity, and the ability to set in a wet environment. Endodontic microsurgery is performed in post-treatment apical periodontitis. iRBP yields promising results as a retrograde filling material. In retrospective studies, 94.4% and 92%% success rates were reported using iRBP.[40,41]

CONCLUSION:

Eliminating the foci of infection is the primary goal of endodontics. As such, a good endodontic material should possess superior anti-microbial properties against root canal pathogens. ERRM possess antimicrobial properties similar to MTA. iRBP Plus is an operator-friendly material exhibiting higher sealing ability and least apical leakage than MTA with similar fracture strength suggesting that it could be a viable alternative for MTA when used in regenerative procedures. The pre-mixed ERRM and iRoot paste eliminate the difficulties in handling the material. Heretofore, iRBP Plus is the only material with the capability of inducing root formation in a non-vital teeth without additional procedures like inducing blood (revascularization) or placement of scaffolds (Platelet rich plasma, platelet rich fibrin). Another advantage is no discoloration is reported using ERRM and iRBP. The application of ERRM is not limited to root repair as it is proved to induce tissue regeneration in apexification and apexogenesis. Studies have proved the effectiveness of the new bioceramic material in various dental therapies.

REFERENCES:

1. Kim SG, Malek M, Sigurdsson A, Lin LM, Kahler B. Regenerative endodontics: a comprehensive review. International endodontic journal. 2018 Dec;51(12):1367-88.
2. Mangat P, Azhar S, Rathore G, Masarat F, Yand N, Sah S. Bioceramics in endodontics: A review. International Journal of Oral Care and Research. 2021 Apr 1;9(2):59.
3. Tomer AK, Kumari S, Rastogi D, Cecilia LL, Singh S, Tyagi A. Bioceramics in Endodontics-A Review. International Journal of Applied Dental Sciences 2020;6(3):588-594.
4. Srinidhi Surya Raghavendra, Ganesh Ranganath Jadhav, Kinjal Mahesh Gathani, Pratik Kotadia. Bioceramics in endodontics – A Review. J Istanbul Univ Fac Dent 2017;51(3 Suppl 1):S128-S137.
5. Alaa E. Dawood, Peter Parashos, Rebecca H.K. Wong, Eric C. Reynolds & David J. Manton. Calcium silicate-based cements: composition, properties, and clinical applications. Journal of Investigative and Clinical Dentistry.2017
6. Mahgoub N, Alqadasi B, Aldhorae K, Assiry A, Altawili ZM, Hong T. Comparison between iRoot BP Plus (EndoSequence Root Repair Material) and Mineral Trioxide Aggregate as Pulp-capping Agents: A Systematic Review. Journal of International Society of Preventive & Community Dentistry. 2019 Nov;9(6):542.
7. Guo Y-J, Du T-F, Li H-B, Shen Y, Mobuchon C, Hieawy A, et al. Physical properties and hydration behavior of a fast-setting bioceramic endodontic material. BMC oral health. 2016 Feb 20;16:23.
8. Lu J, Li Z, Wu X, Chen Y, Yan M, Ge X, Yu J. iRoot BP Plus promotes osteo/odontogenic differentiation of bone marrow mesenchymal stem cells via MAPK pathways and autophagy. Stem cell research & therapy. 2019 Dec;10(1):1-4.
9. Zhang S, Yang X, Fan M. BioAggregate and iRoot BP Plus optimize the proliferation and mineralization ability of human dental pulp cells. International endodontic journal. 2013 Oct;46(10):923-9.
10. Ciasca M, Aminoshariae A, Jin G, Montagnese T, Mickel A. A comparison of the cytotoxicity and proinflammatory cytokine production of EndoSequence root repair material and ProRoot mineral trioxide aggregate in human osteoblast cell culture using reverse-transcriptase polymerase chain reaction. J Endod 2012;38:486–9.
11. Charland T, Hartwell GR, Hirschberg C, Patel R. An evaluation of setting time of mineral trioxide aggregate and EndoSequence root repair material in the presence of human blood and minimal essential media. Journal of Endodontics. 2013 Aug 1;39(8):1071-2.
12. Yazdi KA, Bolhari B, Sabetmoghaddam T, Meraji N, Kharazifard MJ. Effect of Blood Exposure on Push-Out Bond Strength of Four Calcium Silicate Based Cements. Iranian Endodontic Journal. 2017 Spring;12(2):196–200.
13. Abou ElReash A, Hamama H, Eldars W, Lingwei G, El-Din AM, Xiaoli X. Antimicrobial activity and pH measurement of calcium silicate cements versus new bioactive resin composite restorative material. BMC oral health. 2019 Dec;19(1):1-0.
14. Damlar I, Ozcan E, Yula E, Yalcin M, Celik S. Antimicrobial effects of several calcium silicate-based root-end filling materials. Dental materials journal. 2014 Jul 31;33(4):453-7.
15. Lovato KF, Sedgley CM. Antibacterial activity of endosequence root repair material and proroot MTA against clinical isolates of Enterococcus faecalis. Journal of endodontics. 2011 Nov 1;37(11):1542-6.
16. Tian J, Zhang Y, Lai Z, Li M, Huang Y, Jiang H, Wei X. Ion release, microstructural, and biological properties of iRoot BP Plus and ProRoot MTA exposed to an acidic environment. Journal of endodontics. 2017 Jan 1;43(1):163-8.
17. De Souza ET, Nunes Tameirão MD, Roter JM, De Assis JT, De Almeida Neves A, De.Deus GA. Tridimensional quantitative porosity characterization of three set calcium silicate.based repair cements for endodontic use. Microscopy research and technique. 2013 Oct;76(10):1093-8.
18. Seda Aydemir and Hale Cimilli and Parla Meva Gerni and Alperen Bozkurt and Hasan Urucoglu and Nicholas Chandler and Nevin Kartal. Comparison of the Sealing Ability of Biodentine, iRoot BP Plus and Mineral Trioxide Aggregate. Cumhuriyet Dental Journal. 2016 Dec(19):166-171.
19. Zarzour DS, Habib AA, Doumani M, Layous K, Aldajani EH, Alhasan DS, Almarzooq AA. Comparative Evaluation of Sealing Ability of Three Materials Used in Furcal Perforation Repair (In Vitro). World. 2021 May;12(3):179.
20. Noushin Shokouhinejad, Mohammad Hossein Nekoofar, Kazem Ashofteh Yazdi, Shohreh zahraee, Mehrfam Khoshkhounejad. Marginal Adaptation of New Bioceramic Materials and Mineral Trioxide Aggregate: A Scanning Electron Microscopy Study. Iranian Endodontic Journal 2014;9(2):144-148
21. Akcay M, Arslan H, Durmus N, Mese M, Capar ID. Dentinal tubule penetration of AH Plus, iRoot SP, MTA fillapex, and guttaflow bioseal root canal sealers after different final irrigation procedures: A confocal microscopic study. Lasers in surgery and medicine. 2016 Jan;48(1):70-6.
22. Edrees HY, Siddiqui AY, Almousa MM, Ajaj RA, Alshouibi EN, Alothmani OS. The Effect of Two Calcium Silicate Materials on the Fracture Strength of Simulated Immature Teeth during Regenerative Endodontic Treatment. Journal of Evolution of Medical and Dental Sciences. 2021 Aug 16;10(33):2702-7.
23. Guven Y, Tuna EB, Dincol ME, Ozel E, Yilmaz B, Aktoren O. Long-Term Fracture Resistance of Simulated Immature Teeth Filled with Various Calcium Silicate-Based Materials. BioMed research international. 2016;2863817
24. Penmatsa P, Boddeda M, Mandava J, Ravi R, Priyanka A, Pulidindi H. An In-vitro Fracture Strength Assessment of Endodontically Treated Teeth with Different Root-End Materials. European Endodontic Journal. 2021 Dec 1;6(3):319-24.
25. Shokouhinejad N, Razmi H, Nekoofar MH, Sajadi S, Dummer PM, Khoshkhounejad M. Push-out bond strength of bioceramic materials in a synthetic tissue fluid. Journal of Dentistry (Tehran, Iran). 2013 Nov;10(6):540.
26. Yazdi KA, Bolhari B, Sabetmoghaddam T, Meraji N, Kharazifard MJ. Effect of Blood Exposure on Push-Out Bond Strength of Four Calcium Silicate Based Cements. Iranian Endodontic Journal. 2017 Spring;12(2):196–200.
27. Vilas-Boas DA, Grazziotin-Soares R, Ardenghi DM, Bauer J, de Souza PO, de Miranda Candeiro GT, et al. Effect of different endodontic sealers and time of cementation on push-out bond strength of fiber posts. Clinical oral investigations. 2018 Apr;22(3):1403–9.
28. Thibodeau B, Trope M. Pulp revascularization of a necrotic infected immature permanent tooth: Case report and review of the literature. *Pediatr Dent.* 2007;29:47–50.
29. Pooja Nitin Mapara, N D Shashikiran, Sachin Gugawad, Namrata Gaonkar, Savita Hadakar, Swapnil Taur, Dhanshri Khade. Comparative evaluation of calcium release of the apical plugs formed by mineral trioxide aggregate, Biodentine, and EndoSequence root repair material with and without 2% triple antibiotic powder: An in vitro study. J Indian Soc Pedod Prev Dent 2020;38:132-7.
30. Harahap NU, Djauharie N, Asrianti D. Affected dentin remineralization after partial caries excavation (in vivo): the effect of iRoot® BP Plus application. InJournal of Physics: Conference Series 2018 Aug 1;1073(5).
31. Liu S, Wang S, Dong Y. Evaluation of a bioceramic as a pulp capping agent in vitro and in vivo. Journal of Endodontics. 2015 May 1;41(5):652-7.
32. Okamoto M, Takahashi Y, Komichi S, Ali M, Yoneda N, Ishimoto T, Nakano T, Hayashi M. Novel evaluation method of dentin repair by direct pulp capping using high-resolution micro-computed tomography. Clinical oral investigations. 2018 Nov;22(8):2879-87.
33. S. Azimi, M. Fazlyab, D. Sadri, M. A. Saghiri, B. Khosravanifard & S. Asgary. Comparison of pulp response to mineral trioxide aggregate and a bioceramic paste in partial pulpotomy of sound human premolars: a randomized controlled trial. 2013;47.
34. Yang Y, Xia B, Xu Z, Dou G, Lei Y, Yong W. The effect of partial pulpotomy with iRoot BP Plus in traumatized immature permanent teeth: A randomized prospective controlled trial. Dental Traumatology. 2020 Oct;36(5):518-25.
35. Rao Q, Kuang J, Mao C, Dai J, Hu L, Lei Z, Song G, Yuan G. Comparison of iRoot BP Plus and calcium hydroxide as pulpotomy materials in permanent incisors with

complicated crown fractures: A retrospective study. Journal of Endodontics. 2020 Mar 1;46(3):352-7.
36. Niu LN, Jiao K, Wang TD, Zhang W, Camilleri J, Bergeron BE, Feng HL, Mao J, Chen JH, Pashley DH, Tay FR. A review of the bioactivity of hydraulic calcium silicate cements. J Dent. 2014;42(5):517-33.
37. Shokouhinejad N, Nekoofar MH, Razmi H, Sajadi S, Davies TE, Saghiri MA, Gorjestani H, Dummer PM. Bioactivity of EndoSequence root repair material and bioaggregate. Int Endod J. 2012;45(12):1127-34.
38. Sockalingam SNMP, Awang Talip MSAA, Zakaria ASI. Maturogenesis of an Immature Dens Evaginatus Nonvital Premolar with an Apically Placed Bioceramic Material (EndoSequence Root Repair Material®): An Unexpected Finding. Case Rep Dent. 2018 Jun 7.
39. Lei, X G, Qiong Liu, H Qian, Fei Ren, Jingxian Fang, Hedi Liu, Xiaoming Wu, Jing Yang. Comparison of the clinical efficacy of iRoot BP Plus with mineral trioxide aggregate in the pulpotomy of deciduous teeth. Int J Clin Exp Med 2020;13(7):5335-5340.
40. Zhou W, Zheng Q, Tan X, Song D, Zhang L, Huang D. Comparison of mineral trioxide aggregate and iRoot BP plus root repair material as root-end filling materials in endodontic microsurgery: a prospective randomized controlled study. Journal of endodontics. 2017 Jan 1;43(1):1-6.
41. Shinbori N, Grama AM, Patel Y, Woodmansey K, He J. Clinical outcome of endodontic microsurgery that uses EndoSequence BC root repair material as the root-end filling material. Journal of Endodontics. 2015 May 1;41(5):607-12.