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Root-end Filling Materials: A Literature Review

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Abstract: ***Obtaining a hermetic seal between the periodontium and the root canal system is the major objective of root canal treatment. When this hermetic seal is not possible by non-surgical endodontic therapy, apicectomy which is the main part of surgical endodontics should be performed to save the tooth. This surgical endodontics consists of root resection, apical preparation and finally root end filling material to seal the root canal system. This article reviews the suitability of the most common long standing and novel root end filling materials over evolving years.***

Keywords: retrograde filling material, biocompatibility, cytotoxicity, periradicular surgery

1. Introduction

The aim of endodontic treatment is to allow a hermetic seal of all the pathways of communication between pulpal system and periradicular tissues. When non-surgical retreatment fails for any reason, surgical endodontics (apicectomy/root end resection) is a must to save the tooth. To ensure a successful periradicular surgery, proper root-end cavity preparation is a crucial step. Conventionally the preparation of this cavity is done using a round bur mounted on a slow-speed hand piece. Knowing that this technique has been found to have several clinical limitations which include a high risk of root perforation. Recently, the introduction of sonic and ultrasonic devices to clinical practice has shown to resolve the bur limitations. Bertrand et al were the pioneers in reporting on the subject of ultrasonic technique in root end filling [1]. The special feature of this technique is that the ultrasonic tips come in a sorted angulations and shapes which are specifically chosen depending on the location and features of the root resulting in root end-preparation enhancement [2]. In addition, ultrasonic tips have multiple advantages some of which are: carrying out a more conservative osteotomy and achieving root-end resection with negligible ornon-existent bevel angles [3], therefore decreasing the quantity of exposed dentinal tubules and thus the risk of apical leakage [4]. Furthermore, these tips allow the elimination of isthmus tissue existing among two canals in the same root [5] and decreasing the damage of the soft tissue surrounding the root apex throughout the surgical process [6]. Eventually, ultrasonic preparation leads to cleaner, smaller with improved retention and better centrally positioned cavity along the original root canal [7]. Nevertheless, the occurrence of apical micro cracks succeeding root-end preparation has been stated with ultrasonic tips [8]

After root end resection, the root canal system is opened to the periradicular area which allows the passage of bacteria and their byproducts into this system. Root end filling is one of the most important phases of this procedure to prevent recontamination of the root canal system and to maintain an impermeable seal of the apical avenues.

The appropriate requirements for these root end filling materials should include: The ability to prevent leakage of bacteria and their byproducts into the peri-radicular tissues, nontoxic and non-carcinogenic in nature, biocompatibility with the host tissues, insolubility in tissues, dimensionally stable, not affected by the tissue fluids upon setting, easy to handle, radiopaque [9] and ability not to stain the peri-radicular tissues (tattoo) [10]

This article reviews the suitability of the most common long standing and novel root end filling materials over evolving years.

1) GuttaPercha

It is a natural product, chemically composed of trans-isomer of polyisoprene which exists in two crystalline forms: alpha and beta. In 1867, GuttaPercha was introduced and since then its use has been widespread in the endodontic world as a core material which is composed of 20% matrix (gutta-percha), 60% filler (zinc oxide), 11%radioopacifiers (heavy metal sulphates) and 3% plasticizers (waxes)[11].One of the major disadvantages of GuttaPercha is its porous nature that absorbs moisture from peri-apical tissues and initially expands then contracts when used as root end filling material [12]. On the other hand, signs of cortical bone deficiency and increased level of inflammatory intrusion as a sign of non-healing was observed in an in vivo study conducted by Walivaraa et al while he was evaluating bone defect regeneration [13]. Gutta-Percha is no longer recommended as a retrograde filling material due to the advancement of newer materials with considerably better properties.

2) Amalgam

Since the past seven decades amalgam was the most widely used root end filling material and is considered a standard to which all other retrograde filling materials are compared. Although it has many advantages including abundant availability, easy manipulation, and radio-opacity there are several documented disadvantages including moisture sensitivity, marginal leakage, secondary corrosion, and mercury toxicity [14]. Many clinical studies have demonstrated poor results with amalgam as a root end filling material and attributed the failure due to electrochemical corrosion products[15].Moreover, moderate or severe periradicular tissue inflammation was recorded in all roots filled with amalgam. In addition, scattered amalgam particles during root end filling may lead to corrosion which in turn results in an unpleasant tattooing [16]. Other similar studies proved that newly triturated conventional amalgams are highly cytotoxic because of unreacted mercury. This cytotoxicity becomes reduced as the material sets[17.According to Zhu., et al. [18] amalgam shows more cell toxicity to human osteoblast-like cells and periodontal ligament cells than Super-EBA and IRM. Therefore, amalgam cannot be considered anymore as the perfect root-end filling material.

3) Zincoxide–eugenolcements

In 1961, Phillips and Love reported many limitations of zinc oxide eugenol cements when used as a root end filling material which include inherent weakness, long setting time and high solubility that increases it absorption with time[19]. Its use as a root-end filling material has limited documentation [19]. As a consequence the original form was subjected to modifications in order to overcome these disadvantages and enhance their physical properties. One of these modifications lead to the production of Super EBA (ortho-ethoxybenzoic acid which differs from the original form by the replacing part of the eugenol liquid with ortho-ethoxybenzoic acid and adding alumina to the powder)[20]. As a result of these modifications, Super EBA showed high tensile and compressive strength, low solubility, neutral pH and good healing response [14].On the other hand radiolucency, sensitive technique and irritation to the periapical tissue were the major disadvantages encountered [20]. IRM (Intermediate restorative material) is another modification of Zinc oxide-eugenol cement which differs from the original form by the introduction of 20% by weight polymethyl methacrylate to the powder. A comparative study by Al-aseed et al about Zinc oxide-eugenol and its modifications (IRM and Super EBA) showed a higher release of eugenol from IRM when compared to Super EBA due to its higher content of eugenol; in addition, they concluded that the increase of cytotoxicity of these cements due to Zinc content rather than eugenol. Moreover, IRM demonstrated superior seal ability compared to amalgam and Super EBA and have anti-microbial sensitivity against E.faecalis, S.aureus, P.aeruginosa.[21].The main limitation of IRM is the lack of dental hard tissue regenerative capacity[22].

4) GlassIonomer Cements (GIC)

Glass ionomer cement (GIC) comprises of two main parts: aqueous polymeric acids mainly polyacrylic acid and basic glass powders mainly calcium aluminosilicate. Through the aluminosilicate neutralization setting reaction of GIC, a considerable measure of the glass stays unreacted and acts as strengthening filler. This setting reaction could be initiated either chemically or by light activation and both types have been proposed as an alternative retrograde filling material. Improvement of GIC creep resistance, tensile strength and compressive strength by the addition of silver have been proven [23]. Light cured GIC showed a better seal and marginal adaptation when compared to amalgam, IRM and chemically cured GIC as a retrograde filling material[24]. Among the disadvantages of GIC, increased solubility and decreased bond strength occur during the initial setting period due to its vulnerability which is affected by moisture [25].Contamination with blood and moisture during the initial setting period increases its solubility and decreases its bond strength which compromises its use as a root end filling material[26]regarding the cytotoxicity of light and chemical cured GIC, no significant difference was detected when compared to Super EBA or amalgam[27].

5) Composites

In 1987, McDonald and Dumsha compared the extent of leakage among six different types of root end filling materials(composite alone, composite with dentin bonding agent, amalgam, cavit, hot and cold burnished GuttaPercha), composite with dentin bonding agent showed the least amount of leakage and improved the quality of the root end filling when applied directly on the root end[28],[29].When composite resins are properly used, its cytotoxic effects were proved to be reduced or eliminated [30].Modifications of composite is advocated to improve their behavior as root end filling material; Retroplast is one of these modifications where silver particles was replaced with yttrium flouride and ferric oxide. Moreover, this material proved to have high healing response with minimum cementum deposition and insertion of new sharpey's fibers which indicate a tissue regeneration and consequence formation of biologic closure of the root canal [31],[32].Geristore is another light cured composite resin modifications with an attempt to combine the various properties of composite and glass ionomer and became less sensitive to moisture then unmodified glass ionomer cement[33]. It also has regenerative potentials of periradicular ligament fibers to the material surface and the improvement of attachment had been proven with time [34]. Comparative studies assessing leakage behavior of Geristone showed that this material has least leakage among other root end filling materials including IRM, amalgam or Super EBA [35].

6) Mineral trioxide Aggregate (MTA)

Mineral trioxide aggregate (MTA) is a hydrophilic material made of tricalcium silicate, tricalcium aluminate, tricalcium oxide, silicate oxide and Bismith oxide that is added to the powder to make it radiopaque [36]. Since its introduction by Torabinajed & co-workers in 1993, it gained popularity due its biocompatibility, asteogenicity andperiapical tissue regenerative potential [37]. Antibacterial properties of MTA has being proved against S.aureus, E.faecalis, and P.aeruginosa and this activity was found to be exaggerated when 0.12% chlohexidine was added to the MTA mix [38]. Other studies showed that MTA has a higher success rate than amalgam as a root end filling material [39]. In another study, ProRoot MTA showed superiority to Biodentine with respect to sealing ability, yet Biodentine is considered a suitable alternative to ProRoot MTA as aretrograde filling material [40].According to Shetty et al the sealing ability of four different root end filling materials were compared using fluid filtration method . These materials were glass ionomer cement, Biodentine, (MTA)-Plus and MTA Angelus. This study concluded that MTA Angelus followed by Biodentine and MTA Plus proved to have an enhanced sealing ability as a root end filling material [41].

Also in another review comparing the osteogenicability of dental repair materials, it was found that ProRoot-MTA and NeoMTA Plus have osteogenicability because of their biocompatibility [42].

On the other hand, MTA has certain limitations: Difficulty of handling and slow setting reaction which may lead to loss of marginal adaptation, leakage and surface disintegration [43]. A sandy grainy mixture resulting from blending MTA with sterile water, is hard to handle and place in the surgical site and difficult to properly condensed [44]. To overcome this limitation, calcium carbonate is added to MTA resulting inMICRO-MEGA MTA (MMTA) which shows a reduced setting and working. This material is introduced in a capsule form to be utilized after mixing with a mixer of high frequency. This capsule form eases a homogeneous mixture formation, which is hard to obtain using hand instruments, and is cost effective [45].

7) Ceramicrete

It is a ceramic inorganic phosphate binder with an acid-base self-setting reaction that formsa matrix phase(potassium magnesium phosphate hexahydrate ceramic)[46].By adding whiskers of calcium silicate, phosphosilicate ceramic material with an extra dicalcium phosphate dihydrate phasewere formed which resulted in the enhancement of the mechanical properties of Ceramicrete [47].

In 2007, Kelvin et al compared ceramicrete to Super EBA and ProRoot MTA as a root end filling material, the results showed that Ceramicrete fillings are non-porous and have a similar radioopacity to root dentine .Moreover, its sealing ability was shown to be significantly superior to the other two studied root end filling materials [48]. The sealing ability of Ceramicrete, White MTA and Bioaggregate was evaluated by the degree of glucose penetration. Both Ceramicrete and Bioaggregate had comparable sealing ability to MTA, knowing that Ceramicrete was significantly superior to Bioaggregate [49]. Lately, a radiopaque and biocompatible form of this ceramic binder has been proposed through the addition of hydroxyapatite powder and cerium oxide radiopaque fillers, its non-porosity and the release of calcium and phosphate ions during setting of this material allows it to be considered as a root end filling material [50]. This Bioceramic material has an initial and final setting time of 6 minutes and 12 minutes respectively (Gilmore needle method at 37°C), can be handled into a sausage-like formtoease its use with dental instruments, and sets under water having a negligible washout [51].

8) Biodentine

In 2010,Biodentine(calcium silicate based material) mainly constituted of highly purified tricalcium silicate powder which in turn is composed of little amounts of calcium carbonate, dicalciumsilicate, , and a radio-pacifier; while, its liquid form is composed of a setting accelerator (calcium chloride) and a reducing agent (water)[52]. In 2015, Nanjappa et al compared the sealing ability of MTA, Chitra-calcium phosphate cement (CPC) and Biodentine, as a retrograde filling material using Yttrium aluminium garnet laser and endosonic tip for root end preparation. They found that Biodentine filled cavities prepared by laser has a superior sealing ability than all other materials prepared with both laser and ultrasonic [53].On the other hand Biodentine showed a higher solubility when compared with GIC, IRM and MTA as a root end filling material [54]. Moreover, its marginal adaptation showed inferior results in comparison to MTA and IRM root end filling material [55]. Another study compared Biodentine and MTA when utilized as root end filling material; they found that Biodentine presented alkaline pH and capability to release calcium ions when compared to MTA. MTA could be considered as a gold standard as osteoinductive material as well as biodentine might be an alternate to MTA [56]. Biodentine is encapsulated, the capsule is primary mixed using a mixer like that of the amalgamator. Whereas, the needed consistency is manually obtained. Setting time of Biodentine is shorter than that of MTA, it's about 10-12 minutes [57].

9) Bioaggregate

Bioaggregate is a novel bioceramic root repair and retrograde filling material in form of powder and liquid. The powder part is formed of: tricalcium and dicalcium silicate, tantalum pentoxide (radioopecifier), amorphous silicon oxide and calcium phosphate monobasic while the liquid part is composed of deionized water [58].Bolhari et al evaluated the marginal adaptation of bioaggragate compared with MTA, Biodentine, and calcium enriched mixture (CEM) root end filling material in both human blood and normal saline and they found that the marginal adaptation was not affected by blood contamination [59]. In another study, bioaggregate proved to have a significantly less microleakage when compared with other root end filling materials(IRM, White MTA, amalgam, GuttaPercha)[60]. Bioaggregate showed a superior biocompatibility with less inflammatory and foreign body reaction than that of MTA [61]. As reported by the manufacturer, Bioaggregate's working time is at least five minutes. When mixing a paste of thick consistency is created. If an elongated working time is needed, the unattended mixture should be covered with a moist gauze [62].

10) Endosequence

Recently Endosequence Root Repair Material (ERRM) which is composed of three main components: calcium silicates, monobasic calcium phosphate, and zirconium oxide has being introduced. It has many advantages which are radioopacity, bioactivity, biocompatibility and antimicrobial activity due to its high PH [63]. Endosequence has an advantage of enhanced handling and delivery of its products over MTA [62]. Bioactivity of this material was evaluated after exposing it to a phosphate-buffered saline, the results showed that this material is bioactive due to the precipitation of apatite crystalline structures [64]. This material appears to be an appropriate material as a root end filling material in apical surgery since it has biological properties and strengths when compared with MTA. Moreover, it is easy to apply and handle; therefore it is a good alternative to MTA [65]. In a very current in vitro study, in which a scanning electron microscopy was used, EndoSequence showed to have enhanced marginal adaptation and sealing ability when compared to ProRoot MTA sealer [66]. To ease its utilization by the dentist, Endo Sequence is manufactured in a premixed form and is used in a putty consistency. This bioceramic material has a short setting time which is one of its advantages [67].

2. Conclusion

The primary goal of every endodontist surgeon in root end surgery is to achieve a long term success. Therefore, the selection of retrograde filling materials which are extensively studied and proven to be biologically compatible and clinically effective is a must.

Based on this review of literature, all conventional and novel root end filling materials where shown to have points of strength and weaknesses. Knowing that the new root end filling materials are considered to be promising due to their remarkable bioactive characteristics.

References

[1] Bertrand G, Festal F, Barailly R. Use of ultrasound in apicoectomy. Quintessence Int 1976;7:9-12
[2] De Lange, J.; Putters, T.; Baas, E.M.; van Ingen, J.M. Ultrasonic root-end preparation in apical surgery: A prospective randomized study. Oral Surg. Oral Med. Oral Pathol. OralRadiol. Endod. 2007, 104, 841–45.
[3] Mehlhaff, D.S.; Harshall, J.G.; Baumgartner, J.C. Comparison of ultrasonic and high-speed-bur root-end preparations using bilaterally matched teeth. J. Endod. 1997, 23, 448–52.
[4] Gilheany, P.A.; Figdor, D.; Tyas, M.J. Apical dentin permeability and microleakage associated with root end resection and retrograde filling. J. Endod. 1994, 20, 22–26.
[5] vonArx, T. Apical surgery: A review of current techniques and outcome. Saudi Dent. J. 2011, 23, 9–15.
[6] Tsesis, I.; Rosen, E.; Schwartz-Arad, D.; Fuss, Z. Retrospective evaluation of surgical endodontic treatment: Traditional versus modern technique. J. Endod. 2006, 32, 412–16
[7] Endal, U.; Shen, Y.; Ma, J.; Yang, Y.; Haapasalo, M. Evaluation of quality and preparation time of retrograde cavities in root canals filled with GuttaCore and cold lateral condensation technique. J. Endod. 2018, 44, 639–42.
[8] Tawil, P.Z.; Saraiya, V.M.; Galicia, J.C.; Duggan, D.J. Periapical microsurgery: The effect of root dentinal defects on short- and long-term outcome. J. Endod. 2015, 41, 22–27
[9] Gartner AH, Dorn SO. Advances in endodontic surgery. Dent Clin North Am. 1992; 36(2):357-78.
[10] Ingle J,BaklandL,Endodontics.5th Edition 2002
[11] Grossman, Grossman's endodontic practice.12th edition, 2010.
[12] Kaplan SD, Tanzilli JP, Raphael D, Moodnik RM. A comparison of the marginal leakage of retrograde techniques. Oral Surg Oral Med Oral Pathol. 1982; 54(5):583-85.
[13] Wälivaara DA, Abrahamsson P, Isaksson S, Salata LA, Sennerby L, Dahlin C. Periapical tissue response after use of intermediate restorative material, gutta-percha, reinforced zinc oxide cement, and mineral trioxide aggregate as retrograde root-end filling materials: a histologic study in dogs. J OralMaxillofac Surg.2012; 70:2041-47.
[14] Claudio Poggio, Marco Lombardini, Conti Alessandro, RindiSimonetta. Solubility of Root-end filling materials: *A comparative study. J Endod.*2007; *33(9):*1094-97
[15] AndersonRW,PashleyDH,PanteraEA.Microleakageofa malgambondasretrogradefillingsinendodontictherapy.*J Endod.* 1983*; 9:*551-53.
[16] B.S.Chong, T.R.Pitt Ford, S.P.Kariyawasam. Short term response to potential root -end filling materials in infected root canals. IntEndod J. 1997; 30(4): 240-49.
[17] Tronstad LA and Wenneberg D. "In vitro assessment of the toxicity of filling materials". International Endodontic Journal 13.3 (1980): 131-38.
[18] Zhu Q., et al. "Cytotoxic evaluation of root-end filling materials in cultures of human osteoblast-like cells and periodontal ligament cells". Journal of Endodontics 25.6 (1999): 410-12.
[19] PhillipsRW,LoveDR. The effect of certain additive agents on the physical properties of zincoxide-eugenol mixtures.JDentRes.1961;40:294–303
[20] John.M.Yaccino, William.A. Walker, David.L. Carnes, William.G. Schindler. Longitudinal micro leakage evaluation of Super–EBA asaroot-end sealing material,. *JEndod.*1999;*25(8):*552-54.
[21] Al-Sa'eed O,Al-Hiyasat A, Darmani H, The effects of six root-end filling materials and their leachable components on cell viability. J Endod.2008; 34(11):1411-14.
[22] Harrison JW, Johnson SA. Excisional wound healing following the use of IRM as root-end filling material. *JEndod.*1997; 23(1):19-27.
[23] Barkhordar RA, Pelzner RB, Stark MM. Use of glassionomersasretro filling materials. Oral Surg Oral MedOral Pathol.1989;67(6):734-9.
[24] Rosales JI, Vallecillo M, Osorio R, Bravo M, Toledano M. An in vitro comparison of micro leakage in three glass ionomer cements used as retrograde filling materials. *IntDent J.*1996;46(1):15-21.
[25] Gemalmaz D, Yoruc B, Ozcan M, Alkumru HN. Effect ofearlywater contact on solubility of glassionomerluting cements.*JProsthetDent.*1998; 80(4):474-8.
[26] Zetterqvist L,HallG, Holmlund A. A picectomy: A comparative clinical study of amalgam and glassionomercementasapicalsealants. OralSurgOralMedOralPathol.1991; 71(4):489-91.
[27] ChongBS,OwadallyID,PittFordTR,Wilson RF.Cytotoxicityofpotential retrograderoot-fillingmaterials. EndodDent Traumatol.1994; 10(3):129-33.
[28] McDonald NJ, Dumsha TC. A comparative retrofill leakage study utilizing a dentin bonding material. J Endod. 1987; 13(5): 224-8.
[29] Rud J, Munksgaard EC, Andreasen JO, RudV,Asmussen E. Retro grade filling with a

composite and a dentin bonding agent. I. Endont Dent Traumatol. 1991; 7(3): 118-25.
[30] Finne K, Nord PG, Persson G, Lennartsson B. Retrograde root filling with amalgam and cavit. Oral Surg. 1977; 43: 621-26.
[31] Andreasen JO, Munksgaard EC, Fredebo L, Rud J. Periodontal tissue regeneration including cementogenesis adjacent to dentin-bonded retrograde composite fillings in humans. J Endod. 1993; 19:151-3.
[32] Andreasen JO, Rud J, Munksgaard EC: [Retrograde root obturations using resin and a dentin bonding agent: a preliminary histologic study of tissue reactions in monkeys]. *Tandlaegebladet.*1989;93:195-97
[33] Cho E, Kopel H, White SN. Moisture susceptibility of resin modified glass-ionomer materials. Quintessence Int. 1995; 26: 351-8
[34] Camp MA, Jeansonne BG, Lallier T. Adhesion of human fibroblasts to root-end-filling materials. J Endod. *2003;* 29: 602-7
[35] Bohsali K, Pertot WJ, Hosseini B, Camps J. Sealing ability of super EBA and Dyract as root-end fillings: a study in vitro. IntEndod J. 1998; 31: 338-42
[36] Pitt Ford TR, Torabinejad M, McKendry DJ, Hong CU, Kariyawasam SP. Use of mineral trioxide aggregate for repair of furcal perforations. Oral Surg Oral Med Oral Pathol Oral RadiolEndod. 1995; 79(6): 756-63.
[37] William Philip Saunders. A prospective clinical study of periradicular surgery using Mineral trioxide aggregate as a root-end filling. J Endod. 2008;34(6):660-64.
[38] Stowe TJ,Sedgley CM, Stowe B, Fenno JC. The effects of chlorhexidine gluconate (0.12%) on the anti-microbial properties of tooth-coloured Pro-root MTA. J Endod. 2004;30(6), 429-31
[39] Wahid A, Khan I, Ahmad B,Raza M.Comparison of mineral trioxide aggregate (MTA) and zinc free amalgam as retrograde filling materials in the surgical endodontics. Pak Oral Dental J. 2014; 34(2): 352-4
[40] Nabeel M, Tawfik HM, Abu-Seida AMA, Elgendy AA. Sealing ability of Biodentine versus ProRoot mineral trioxide aggregate as root-end filling materials. Saudi Dent J 2019;31(1):16–22.
[41] Shetty S, Hiremath G, Yeli M, A comparative evaluation of sealing ability of four root end filling materials using fluid filtration method: An in vitro study. J Conserv Dent. 2017;20(5):307-10.
[42] Alghamdi Faisal. “The Biological Effect of the Endodontic Bioactive Cements Fast Set Neomta Plus and Proroot-Mta on Osteogenic Differentiation of Mesenchymal Stem Cells: A Systematic Review”. International Dental Journal of Student’s Research 7.2 (2019): 24- 28.
[43] Girish CS, Ponnappa K, Girish T, Ponappa M. Sealing ability of mineral trioxide aggregate, calcium phosphate and polymethylmethacrylate bone cements on root ends prepared using an Erbium: Yttriumaluminium garnet laser and ultrasonics evaluated by confocal laser scanning microscopy. J Conserv Dent. 2013;16:304–8
[44] P. Kogan, J. He, G.N. Glickman, I. WatanabeThe effects of various additives on setting properties of MTA J. Endod., 32 (6) (2006), pp. 569-72
[45] Tanalp J, Karapinar-Kazandag M. Comparison of the radio opacities of different root-end filling and repair materials. Scientific World Journal. 2013;2:1-13.
[46] Chattopadhyay S. Evaluation of chemically bonded phosphate ceramics for mercury stabilization of a mixed synthetic waste. National Risk Management Research Laboratory, US Environmental Protection Agency, EPA/600/R-03/113, 2003
[47] Wagh AS, Jeong SY, Lohan D, Elizabeth A. Chemically bonded phospho-silicate ceramic. U.S. Patent No. 6,518,212. US Patent & Trademark Office, 2003.
[48] Kelvin C.Y. Tay, Bethany A.Loushine, Cindy Oxford, Rishi Kapur, Carolyn M. Primus, James L. Gutmann, Robert J.Loushine, David H. Pashley, Franklin R. Tay. In vitro evaluation of a Ceramicrete-based Root-end filling material. J Endod. 2007; *33(12)*: 1438-43
[49] F.Leal, G.De-Deus, C.Brandao, A.S.luna, S.R.Fidel, E.M.Souza. Comparison of the root-end seal provided by bioceramic repair cements and white MTA.IntEndod J. 2011; 44(7): 662-68.
[50] Kelvin C.Y.,Bethany A Loushine., Cindy Oxford, ,Rishi Kapur, , Carolyn M.Primus, James L.Gutmann, Robert J. Loushine,David H. Pashly, Franklin R. In Vitro Evaluation of Cermicrete-based Root-end Filling Material.2007,J Endod;33:1438-43
[51] Wagh AS, Primus C. Method and product for phosphosilicate slurry for use in dentistry and related bone cements. US Patent No. 7,083,672. US Patent & Trademark Office, 2006.
[52] A.R.Atmeh, E.Z.Chong, G.Richard, F.Festy, T.F.Watson, Dentin-cement interfacial interaction: Calcium silicates and Polyalkenoates, Journal of dental research 2012 , 91(5): 454-59
[53] Nanjappa AS, Ponnappa KC, Nanjamma KK, Ponappa MC, Girish S, Nitin A. Sealing ability of three root-end filling materials prepared using an erbium: Yttrium aluminium garnet laser and endosonic tip evaluated by confocal laser scanning microscopy. J Conserv Dent. 2015;18(4):327-30.
[54] Singh S, Podar R, Dadu S, Kulkarni G, Purba R. Solubility of a new calcium silicate-based root-end filling material. J Conserv Dent. 2015;18(2):149-53.
[55] SoundappanS,Sundaramurthy J, Raghu S, Natanasabapathy V. Biodentine versus Mineral Trioxide Aggregate versus Intermediate Restorative Material for Retrograde Root End Filling: An Invitro Study. JDent. 2014; 11(2):134-49.
[56] Paula Anabela., et al. “Biodentine™ Boosts, Whiteproroot® Mta Increases and Life® Suppresses Odontoblast Activity”. Materials 12.7 (2019): 1184
[57] Setbon HM, Devaux J, Iserentant A, Leloup G, Leprince JG. Influence of composition on setting kinetics of new injectable and/or fast setting tricalcium silicate cements. Dent Mater. 2014 ; 30(12):1291-303.
[58] Hashem AA, Wanees Amin SA. The effect of acidity on dislodgment resistance of mineral trioxide aggregate and bioaggregate in furcation perforations: an in vitro comparative study. J Endod. 2012;38(2):245-9.

[59] BolhariB, Yazdi1 K, Sharifi F, Pirmoazen S.Comparative scanning electron microscopic study of the marginal adaptation of four root-end filling materials in presence and absence of blood,J Dent. 2015;12, 3:226-34.

[60] El Sayed MA, Saeed MH. In vitro comparative study of sealing ability of Diadent Bioaggregate and other root-end filling materials. J conserv dent. 2012; 15(3): 249-52.

[61] Yusuf-BurakBatur, GozdeAcar, YagmurYalcin, SeckinDindar, HandeSancakli, UgurErdemir. The cytotoxic evaluation of mineral trioxide aggregate and bioaggregate in the subcutaneous connective tissue of rats. Med oral Patol Oral Cir Bucal. 2013; 18(4):745-51

[62] Madfa A, Al-Sanabani F, Al-Qudami N. Endodontic repair filling materials: a review article. Br J Med Med Res. 2014;4(16): 3059-79

[63] N.Shokouhinejad, M.H.Nekoofar, H.Razmi, S.Sajadi, T.E.Davies, M.A.Saghiri, H.Gorjestani, P.M.H.Dummer. Bioactivity of Endosequence Root Repair Material and Bioaggregate. IntEndod J. 2012; 55(12):1127-34.

[64] Maria Ciasca, Anita Aminoshariae, Thomas Montagnese, Andre Mickel. 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;35(4):421-25

[65] Zafar K, Jamal S, Ghafoor R. Bio-active cements-Mineral Trioxide Aggregate based calcium silicate materials: a narrative review. J Pak Med Assoc. 2020;70(3):497-504.

[66] Patri G, Agrawal P, Anushree N, Arora S, Kunjappu JJ, Shamsuddin SV. A Scanning Electron Microscope Analysis of Sealing Potential and Marginal Adaptation of Different Root Canal Sealers to Dentin: An In Vitro study. J Contemp Dent Pract. 2020;21(1):73-77.

[67] NicaLuminița Maria, Boscornea-PușcuAndreea-Simona, HorhatRăzvan Mihai1, Karsoua Mona, Cîrligeriu Laura Elena. Comparison of three calcium silicate cements used as retrograde filling materials. an in vitro study. Research and Clinical Medicine. 2020, 4(1):32-36