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ROOT END FILLING MATERIALS AND RECENT ADVANCES: A REVIEW

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ABSTRACT The main objective of an endodontic procedure is to obtain a hermetic seal between root canal space and the periapical tissues and when this is not achieved by an orthograde approach, then a root end filling technique is used. Numerous materials have been suggested for use as root-end fillings. Earlier amalgam was considered the material of choice but recently MTA has been developed which fulfils almost all the requirements of an ideal root end filling material. This article reviews different root-end filling materials and compare their biocompatibility, sealing ability, anti-bacterial effects and microleakage.

KEYWORDS : Root end filling materials, Sealing ability, Fluid tight seal, Microleakage, Biocompatibility

INTRODUCTION

A mandatory requirement of root canal therapy is that the obturation and restoration of the tooth must seal the root canals both apically and coronally to prevent leakage and percolation of oral fluids and to prevent recontamination of disinfected canals. Apicoectomy (apicectomy/root-end resection) with retrograde obturation is a widely applied procedure in endodontics, when all efforts for the successful completion of orthograde endodontic therapy have failed. Failure of non-surgical endodontic treatment or non-surgical endodontic retreatment indicates the need for endodontic surgery to save the tooth. Ideal requirements of a root end filling material are [2,3,4]

1. Adhere and adapt to the walls of the root preparation
2. Prevent leakage of microorganisms and their products into the periradicular tissues
3. Be biocompatible
4. Nonresorbable
5. Unaffected by moisture
6. Easy to prepare and place
7. Radiographically visible
8. To have anticaries activity
9. To be non-toxic, non-carcinogenic, dimensionally stable
10. It should not cause paresthesia
11. It should not cause additional pigmentation
12. It should not corrode or be electrochemically active
13. It should have bactericidal or bacteriostatic effect
14. It should stimulate cementogenesis
15. It should be well tolerated by periradicular tissues with no inflammatory reactions

Numerous root end filling materials are there but no material has been found to fulfill all the properties for an ideal retrograde filling. Following are the commonly used root end filling materials. Amalgam has been first material of choice for a root end filling for many years. Other metals such as gold-foil, titanium screws and gallium alloy are also used.

Cements such as glass ionomers, Super EBA, IRM (zinc oxide-eugenol cements), carboxylate cements, zinc phosphate cements, calcium phosphate cement, Diaket, and mineral trioxide aggregate (MTA) are also used for retrograde filling. Composite resins and gutta-percha are also widely used. Rarely used Root-end filling materials includes laser, citric acid demineralization, teflon, ceramic inlay.

AMALGAM

Amalgam is one of the oldest and commonly used root end filling material. Farrar (1884) was the first one to place it as a root-end filling subsequent to resection. Later Rhein (1897), Faulhaber & Neumann (1912), Hippels (1914) and Garvin (1919) also used it for root-end fillings. It is easy to manipulate, has self sealing capacity, is radio-opaque and insoluble in tissue fluids because of the formation of corrosion products. The preferred amalgam is high copper-zinc free. It remains as a standard to which other materials are compared. Clinical and histopathological studies show that amalgam, implanted subcutaneously and adjacent to bone is well tolerated by periapical tissues.[5,6]

According to few studies, amalgam when used in combination with Amalgabond has a better sealing ability.[7] Georgiev et al[8] reported a clinical case of paresthesia due to disseminated amalgam retrograde filling in the upper jaw and soft tissues. Studies by Tronstad et al and Abdul et al[10] have found that the apical seal is significantly improved when varnish was applied to the cavity prior to the placement of a retrograde amalgam filling. Other comparative studies showed that freshly mixed conventional amalgams are very cytotoxic due to unreacted mercury with cytotoxicity decreasing as the material hardens. Scientists show concern about the free mercury and its potential toxicity.[11] Zhu et al[12] suggested that amalgam had a higher cell toxicity to human periodontal ligament cells and human osteoblast-like cells than IRM and Super-EBA.

Amalgam has few limitations which includes production of corrosive by products.[13,14] Others include possibility of mercury and tin contamination, moisture sensitivity, for retention need of a retentively designed cavity preparation, staining of hard and soft tissues and non resorbable scattered particles which may be difficult to retrieve.[15]

Also, it does not seal the root end three-dimensionally and does not prevent the leakage of microorganisms and their products in the periradicular tissues. [16,17] Many clinical studies have shown poor outcomes with amalgam root-end fillings and amalgam can no longer be considered as the ideal root-end filling material.[18] Due to these reasons in recent times, amalgam is not a favourite material for root end filling.

GUTTA-PERCHA

Another most commonly used material for retrograde filling is gutta percha. It is known to have a poor sealing ability as it has to be used with a sealer during root canal obturation. A study observed that heat sealed gutta-percha provides a better seal as compared to Amalgam, IRM and Super EBA.[10] It is reported that a better seal can be obtained with thermo-plasticized gutta-percha than amalgam with and without varnish. [19,20,21] It is nonresorbable, biocompatible and has good handling properties but at the same time its moisture sensitive. Also there is a tendency for its margins to open when the canal root interface is cut, heated or burnished.

ZINC OXIDE EUGENOL CEMENTS

Because of their more solubility that caused periapical tissue irritation, these materials were to subjected to various modifications. The most commonly used zinc oxide cements are Super EBA and IRM. Super EBA is 60% zinc oxide, 30% alumina, 6% natural resin, with the liquid being 37.5% eugenol and 62.5% orf/ 70-ethoxybenzoic acid. IRM is 80% zinc oxide, 20% polymethylmethacrylate, with the liquid being 99% eugenol. They have excellent sealing capability and are non toxic after setting. But are moisture sensitive and cause initial tissue irritation.

The use of Super EBA for root-end filling material was first suggested in 1978. The collagen fibers grew over Super EBA root-end fillings and claimed the material to be biocompatible.[22] Baek et al compared the periapical tissue responses and cementum regeneration in response to three widely used root-end filling materials, amalgam, SuperEBA, and Mineral Trioxide Aggregate (MTA) and found that Super EBA was superior to amalgam as a root-end filling material.[23] Torabinejad M et al examined the tissue reaction of implanted Super-EBA and MTA in the mandibles of guinea pigs. Two bony cavities with- out implanted materials were left to heal and used as negative controls. The presence of inflammation, predominant cell type, and thickness of fibrous connective tissue adjacent to each implant was recorded. Based on these results, it seems that both Super-EBA and MTA are biocompatible.[24]

Pitt Ford TR et al examined also the effect of IRM root end fillings on healing after replantation in 21 molar teeth in monkeys and concluded that the tissue response to root-end fillings of IRM in replanted teeth was less severe and less extensive than that to amalgam.[25] Harikaran et al evaluated the sealing ability of tree different materials for retrograde filling and revealed that the dye leakage scores were lowest in IRM. The sealing ability of IRM was significantly better than amalgam and glass-ionomer.[26] Trope et al in a histological study confirmed the good tissue response to both EBA and IRM. [27]

CAVIT

It is a temporary filling material made of zinc oxide and zinc sulphate without eugenol. Evaluation of the sealing ability of amalgam, Cavit and glass ionomer cement was done to reveal that Cavit had a better seal than amalgam but the seal was inferior to that of amalgam.[28] Cavit is soft when placed in the tooth and sub- sequently undergoes a hygroscopic set after per- meation with water, giving a high linear expansion (18%). This rationalizes its use as a root-end filling material. Cavit has been shown to exhibit greater leakage than IRM.[29] It is not proved that it is toxic or non-toxic that is why using Cavit is not recommended as retrograde filling .[30,31]

GLASS IONOMER CEMENT

Glass ionomers are formed by the reaction of calcium–aluminosilicate glass particles with aqueous solutions of polyacrylic acid. It bonds physico- chemically to dentine. These cements are easy to handle and does not cause any adverse histological reaction in the periapical tissue [32,33] According to MacNeil K et al sealing ability of GIC was adversely affected when the root end cavities were contaminated with moisture at the time of placement of cement.[34] A study used light cure, resin reinforced GIC as a retro- grade filling material. It showed least microleakage due to less moisture sensitivity, less curing shrinkage and deeper penetration of polymer into dentin surface.[35] It is reported that newer glass ionomer cements containing glass-metal powder have less leakage and showed no pathologic signs.[36] One of the disadvantage of glass ionomers is the root preparation must be absolutely dry and seal is adversely affected by moisture and low pH.

COMPOSITE RESIN

Composite resins are used as a retrograde filling with a bonding agent. Conventional composite resins contain a polymerizable organic matrix, inorganic fillers and a silane coupling agent. TEGDMA, bis-GMA and UDMA have been detected in aqueous extracts[37] and formaldehyde can liberate over a long time period.[38] These components may be the reason why the material exhibits highly anti-bacterial effects against P.gingivalis, P.intermedia, P.endodontalis, F.nucleatum.[39]

Rud et al have reported on several prospective and retrospective human usage studies in an attempt to evaluate the acceptability of composite resin combined with a dentin-bonding agent as a retrograde filling. They applied Gluma in vivo to cases requiring periradicular surgery and compared it to cases treated with root-end amalgam fillings. Gluma exhibited complete healing in 74% of the cases as compared to amalgam healing only in 59% of cases.[40] Another study demonstrated excellent long term clinical success with the use of retroplast composite resin and Gluma bonding agent. Using composite resin for retrograde filling allows for more conservative preparation of the root- end cavity. Slightly concave root-end preparations is suggested followed by bonding to the entire resected root end.[41] They are sensitive to moisture than conventional glassionomer cements.

TITANIUM SCREWS

A study of titanium screws as retrograde fillings was done to compare it with amalgam. Bacterial penetration was seen readily on the first day in the amalgam fillings but bacteria penetrated the titanium screw seals after 2 to 7 days. Titanium screws appeared to produce a tighter seal than amalgam.

DIAKET

Diaket is a root canal sealer but in thicker consistency is used as a root-end filling material. As a root-end filling, diaket is shown to have superior sealing qualities when compared to amalgam.[43] Diaket also shows a good healing response characterized by bone apposition, reformation of periodontal ligament and deposition of new cementum.[44]

GOLD FOIL

The use of gold foil as a root-end filling material was first reported by Schuster in 1913 and Lyons in 1920. It exhibits perfect marginal adaptability, surface smoothness and tissue biocompatibility. Implants of gold foil produce only mild tissue reaction.[45] Gold Foil was found to be the best apical sealing material as far as the improvement in biting force is concerned.[46] When compared to IRM, composite resin, amalgam and glass ionomer, goldfoil was least toxic.[47] The routine use of gold foil as a root-end filling material does not appear practical because it requires a moisture free environment, careful placement and finishing.

CALCIUM PHOSPHATE CEMENT (CPC)

CPC is mixture of two calcium phosphate compounds, one acidic and the other basic.[48] It is commonly known as hydroxyapatite cement and is composed of tetracalcium phosphate and dicalcium phosphate reactants. These compounds, when mixed with water, react isothermally to form a solid implant composed of carbonated hydroxyapatite.[49] It is as radio opaque as bone. When combined by dissolution in moisture, even blood, CPC sets into hydroxyapatite.[50] It demonstrates excellent biocompatibility, does not cause a sustained inflammatory response or toxic reaction. An *in vivo* monkey study found new bone formation developing immediately adjacent to CPC.[48]

MINERAL TRIOXIDE AGGREGATE

Mineral trioxide aggregate (MTA) was developed by Torabinejad at Loma Linda University, CA, USA in 1993. MTA cement is commercialized in two different versions, grey and white (Grey and White MTA). The main difference between the two versions is the highest concentration of iron oxide in the Grey MTA, which, according to several studies, is the main responsible for dental tissues staining when the material is used.[51] It consists of calcium and phosphorous ions, derived primarily from tricalcium silicate, tricalcium aluminate, tricalcium oxide and silicate oxide. Its pH when set is 12.5 and its setting time is 2 hours and 45 minutes. The compressive strength of MTA is reported to be 40 MPa immediately after setting and increases to 70MPa after 21 days. [52]

Several dye leakage studies have demonstrated the fact that MTA leaks significantly less than other root-end filling materials. Fischer et al [53] determined the time needed for *Serratia marcescens* to penetrate a 3 mm thickness of zinc-free amalgam, Intermediate Restorative Material (IRM), Super-EBA, and MTA when these materials were used as root- end filling materials. The number of days required for *S. marcescens* to penetrate the four root-end filling materials and grow in the phenol red broth was recorded and analyzed. They reported that most of the samples filled with zinc-free amalgam leaked bacteria in 10 to 63 days. IRM began leaking in 28 to 91 days. Super-EBA began leaking in 42 to 101 days. MTA did not begin leaking until day 49. At the end of the study, four of the MTA samples had not exhibited any leakage. Statistical analysis of the data indicated Mineral Trioxide Aggregate to be the most effective root-end filling material against penetration of *S. marcescens*.

Apaydin et al[54] compared the effect of fresh MTA with set MTA on hard-tissue healing after peri- radicular surgery in the root canals of 24 mandibular premolars in four 2-yr-old beagle dogs. They found that there is no significant difference in the quantity of cementum or osseous healing associated with freshly placed or set MTA when used as root-end filling material. Lindeboom et al[55] performed a randomized clinical prospective study to evaluate the application of MTA and IRM as retrograde sealers in surgical endodontics. One hundred single-rooted teeth were surgically treated. After randomization, MTA or

IRM was used as a retrosealer. Radiographs were taken 1 week, 3 months, and 1 year postoperatively. Complete healing was observed in 64% of the MTA treated teeth vs 50% of the IRM treated teeth. Incomplete healing was seen in 28% (MTA) vs 36% (IRM), and unsatisfactory in 6% (MTA) vs 14% (IRM). Only 1 failure was seen (MTA). No statistically significant differences were found between the two retrofilling materials. The marginal adaptation of MTA was better with or without finishing when compared to IRM and Super EBA.[56] MTA, when used as a root-end- filling material, showed evidence of healing of the surrounding tissues.[57,58] Most characteristic tissue reaction of MTA was the presence of connective tissue after the first postoperative week.

NEWER MATERIALS

CASTOR OIL POLYMER

It is a new material which is obtained from a tropical plant called Riccinus communis. It is a biopolymer consisting of a chain of fatty acids. It is shown to be biocompatible, non-toxic and easy to handle.[60] Compared to MTA and GIC, it showed decreased dye penetration.

BIOAGGREGATE

Bioaggregate is a modification of MTA. It is a new bioceramic root repair and root-end filling material composed of a powder component consisting of tricalcium silicate, dicalcium silicate, tantalum pentoxide, calcium phosphate monobasic and amorphous silicon oxide and a liquid component of deionized water. The effect of Bioaggregate and MTA on human pulp and PDL cell growth was determined by examining the cells grown on this cement using a phase microscope. An inhibition zone was detected in the pulp and PDL cell culture grown with MTA. Bioaggregate showed no inhibition zone around the material. Bioaggregate was found to be non- toxic to human pulp and PDL cells. [61]

A study investigated the cytotoxicity and the effect of Bioaggregate on Mineral-associated gene expression in osteoblast cells. In a study done to compare the cytotoxicity of ProRoot MTA and DiaRoot Bioaggregate, Bioaggregate showed a significantly better inflammatory reaction and foreign body reaction than the MTA group. Bioaggregate appeared to be more biocompatible than MTA.[62] An in vitro comparative study of the sealing ability of Diadent Bioaggregate and other root-end filling materials (Gutta-percha, amalgam, IRM, White MTA) was done using methylene blue dye penetration technique. The results showed that microleakage was significantly less in Bioaggregate when compared to amalgam, IRM and White MTA.[63] Bioaggregate was shown to be non-toxic to osteoblast cells and it was also shown to enhance expression of genes for collagen type 1, osteopontin and osteocalcin, which are genes associated with mineralization in osteoblast cells. [64]

BIODENTINE

It is a calcium silicate based material introduced in 2010 and is used as a material for crown and root dentin repair treatment, repair of perforations, apexifications, resorption repair and root-end fillings.[65] The main component is a highly purified tricalcium silicate powder that contains small amounts of dicalcium silicate, calcium carbonate, and a radioopaquer. The interfacial properties of dentin-biodentine interface were studied under microscope and tag-like microstructures were detected. The flowable consistency of Biodentine penetrates dentinal tubules and helps in the mechanical properties of the interface.[66] Investigation of the bioactivity of Biodentine, MTA and a new Tricalcium silicate cement revealed that all three cements allowed the deposition of hydroxyapatite on the surface. This shows that all three materials are bioactive.[67] An in vitro study to compare the sealing ability of MTA, Calcium phosphate cement and Biodentine MTA showed the highest seal and the least dye absorbance. Biodentine showed a seal slightly less than MTA but, higher than Calcium phosphate cement.[68]

CERAMICRETE

This material has hydroxyapatite powder and cerium oxide radioopaque fillers. This material is biocompatible and radiopaque and is also known to release calcium and phosphate ions during setting.[69] It is a self-setting phosphate ceramic that sets using an acid-base reaction to form a potassium magnesium phosphate hexahydrate ceramic matrix phase. Its mechanical properties were improved by adding calcium silicate whiskers to produce a phosphosilicate ceramic material.[70] A comparison of the root-end seal achieved using Ceramicrete, Bioaggregate and White MTA was done to study the prevention of glucose penetration. Both Bioaggregate and Ceramicrete showed similar sealing ability to MTA, with Ceramicrete showing significantly better results than Bioaggregate. [71]

An in vitro study was done to evaluate the Ceramicrete based material as a root-end sealing material. This study used a ceramicrete-based powder mixed with deionized water. This study showed that ceramicrete had a radioopacity similar to root dentin, and the sealing ability was higher compared to a SuperEBA and ProRoot MTA group. This excellent apical seal was attributed to its impervious nature and also the use of an acidic $MgH_2PO_4.H_2O$ solution as a conditioner to remove the smear layer which is believed to have improved the adaptation of ceramicrete with the dentin. On immersion of the set ceramicrete material in a Phosphate containing fluid (PCF), there was formation of Dicalcium phosphate dihydrate (DPCD) or hydroxapatite on the surface. This is due to the reaction of calcium disilicate from the ceramicrete material with the phosphate from the PCF. Thus, ceramicrete shws potential bioactivity. [72]

ENDOSEQUENCE (ERRM)

It is a new bioceramic material consisting of calcium silicates, monobasic calcium phosphate, and zirconium oxide. Its is radioopaque, biocompatible, bioactive and its high pH contributes to its antimicrobial activity. ERRM has been shown to have negligible cytotoxicity and capability to induce cytokine expression similar to MTA. The bioactivity was tested in a study by exposing the set material in phosphate-buffered saline. There was precipitation of apatite crystalline structures, which is indicative of its bioactivity. [74]

iROOT BP PLUS

iRoot BP Plus (Innovative BioCeramix Inc., Canada) is a synthetic water-based bioceramic cement. It is available in ready to use premixed form and has a biocompatibility similar to MTA. [75]

GENEREX A

Generex A (Dentsply Tulsa dental, USA) is a calcium silicate based cement and is similar to MTA but the handling properties are different. Instead of water the cement is mixed with a special gel. The final consistency is similar to IRM like dough and easy to manipulate. [76]

CAPASIO

Capasio (Primus Consulting, Bradenton, FL) is a calcium-phospho-aluminosilicate–based cement that uses a novel setting reaction and has demonstrated similar or improved physical characteristics such as setting time, radiopacity, compressive strength, pH, and washout resistance.[76] Such favorable properties make Capasio a potential root-end filling material; however, evidence is still lacking to justify the use of this material as an improvement over MTA.

EPOXY RESIN AND PORTLAND CEMENT (EPC)

Epoxy resin and Portland cement (EPC) is made from a mixture of epoxy resin and Portland cement. In vitro studies show that it has a good radio opacity, short setting time, low microleakage, and low cytotoxicity and can be used a root end filling material. [77]

ENDOBINDER

EndoBinder (Binderware, Brazil) is a new calcium aluminate cement. During production, free magnesium oxide and calcium oxide are eliminated to avoid expansion of the material and ferric oxide which can cause tooth discolouration is also eliminated. Aguilar et al evaluated the biocompatibility of a calcium aluminate based-cement (EndoBinder) in subcutaneous tissue of rats, in comparison with the grey version of MTA. After 42 days, EndoBinder presented no inflammatory reaction, however, a mild inflammatory reaction was observed for MTA, in the same period of analysis, which denotes the presence of a chronic inflammatory process.[78]

Recently tetrasilicate cements are being considered as a good alternative root end filling material. In vitro studies show that their properties are similar to that of MTA. [79]

CONCLUSION

An ideal root-end filling material should meet the following characteristics which includes to provide a hermetic seal, to be nonresorbable, non-toxic, non-carcinogenic, biocompatible and dimensionally stable. Of all the materials available, none satisfies all of the desired qualities. Based on various studies, dental amalgam should no longer be used because of its inadequate sealing, poor marginal adaptation and cytotoxic effect and and of all the recent root end filling materials, MTA remains to be the material of choice and is considered the gold standard for all the future root end filling materials.

REFERENCES:

1. Gutmann and Harrison, Gutmann's surgical endodontics, 1999.
2. Ingle JI, Leif K, Bakland, JC Baumgartner. Ingle's Endodontics 6. Hamilton: BC Decker Inc; 2008. pp 1233-1294.
3. Arens DE, Torabinejad M, Chivian N, Rubinstein R. Practical Lessons in Endodontic Surgery. Quin- tessence Publishing; 1998. pp 121-123.
4. Dorn SO, Gartner AH. Advances in endodontic surgery. Dent. Clin.Amer. 1992;36:357-379.
5. Flanders H, Garth A, Burch B, Dockum N. Comparative histopathologic study of zinc free amalgam and Cavit in connective tissue of the rat. J Endod. 1975;1:56-59.
6. Marcotte L, Dowson J, Rowe N. Apical healing with retrofilling materials amalgam and gutta-percha. J Endod. 1975;1(2):63-5.
7. Anderson RW, Pashley DH, Pantera EA :Microleakage of Amalgam bond in endodontic retrofillings. J Endod. **17**: 198 (1991).
8. Georgiev T, Peev S, Papanchev G, Borisova-Papancheva Ts, E Aleksieva. A clinical case of paresthesia due to amalgam retrograde filling disseminated in the upper jaw and soft tissues. Scripta Scientifica Medica. 2012;44(2):97-101.
9. Tronstad L, Trope M, Doering A, Hasselgren G. Sealing ability of dental amalgams as retro- grade fillings in endodontic therapy. J Endod. 1983;8:551-553.
10. Abdul K, DH Retief, HC Jamison. The apical seal via the retrosurgical approach. II. An evaluation of retrofilling materials. Oral Surg. 1982:54:213-8.
11. Tronstad LA, Wenneberg D. In vitro assessment of the toxicity of filling materials. Int End J. 1980;13:131-138.
12. Zhu Q, Safavi KE, Spangberg LS. Cytotoxic evalua- tion of root-end filling materials in cultures of human osteoblast-like cells and periodontal ligament cells. Endod. 1999 Jun;25(6):410-2.
13. Hohenfeldt PR, Aurelio JA, Gerstein H. Electro- chemical corrosion in the failure of apical amalgam. Report of two cases. Oral Surg Oral Med Oral Pathol. 1985;60(6):658-60.
14. Pleva J. Corrosion and Mercury Release from Dental Amalgam. Journal of Orthomolecular Medicine. 1989;4(3):141-158.
15. Gartner AH, Doran SO. Advances in endodontic surgery. Dent. Clin. N. Amer. 1992; 36: 357-379.
16. Georgiev T, Peev S, Papanchev G, Borisova-Pa- pancheva Ts, E Aleksieva. A clinical case of paresthesia due to amalgam retrograde filling disseminated in the upper jaw and soft tissues. Scripta Scientifica Medica. 2012;44(2):97-101.
17. Pereira CL, MS Cenci, FF Demarco. Sealing ability of MTA, Super EBA, Vitremer and amalgam as root-end filling materials. Braz Oral Res; 2004;18(4):317-21.
18. B.S.Chong, T.R.Pitt Ford, S.P.Kariyawasam, Short term response to potential root-end filling materials in infected root canals. International Endodontic journal,(30), 1997, 240-249.
19. MacPherson MG, Hartwell GR, Bondra DL, Weller RN. Leakage in vitro with high-temperature thermoplaticized gutta-percha, high copper amalgam and warm gutta percha when used as retrofilling material. J Endod. 1989;15:212-5.
20. Woo YR, Wassel RW, Foreman PC. Evaluation of sealing properties of 700C thermoplasticized gutta-percha used as a retrograde root filling. Int Endod J. 1990;23:107-12.
21. Wu MK, Dean SD, Kersten HW. A quantitative microleakage study on a new retrograde filling technique. Int Endod J. 1990;23:245-9.
22. Oynick J, Oynick T. A study of a new material for retrograde fillings. J Endod. 1978 4(7):203-6.
23. Baek SH, Plenk H Jr, Kim S. Periapical tissue responses and cementum regeneration with amalgam, SuperEBA, and MTA as root-end filling materials. J Endod. 2005;31:444-449.
24. Torabinejad M, Hong CU, Pitt Ford TR, Kaiyawasam SP. Tissue reaction to implanted Super- EBA and mineral trioxide aggregate in the mandible of guinea pigs: a preliminary report. J Endodon 1995;21:569-571.
25. Pitt Ford TR, Andreasen JO, Dorn SO, Kariyawasam SP. Effect of IRM root end fillings on healing after replantation. J Endod. 1994 Aug;20(8):381-5.
26. Harikaran K, Narayanan L. Evaluation of two different root-end preparations. JIADS. 2010;3:01-06.
27. Trope M, Lost C, Schmitz HJ, Friedman S. Healing of apical periodontitis in dogs after apicoectomy and retrofilling with various filling materials Oral Surg Oral Med Oral Pathol. 1996;81:221-228.
28. Hatem A. Alhadainy, Van T. Himel, Evaluation of the sealing ability of amalgam, Cavit and Glass ionomer cement in the repair of furcation perforation, Journal of oral medicine, oral surgery and oral pathology, 75(3), 1993, 362-366.
29. Friedman S, Shani J, Stabholz A, Kaplawi. Comparative sealing ability of temporary filling materials evaluated by leakage of radio sodium. Int Endod J. 1986;19:187-93.
30. Al-Nazhan S, Sapounas G, Spangberg LSW. In vitro study of the toxicity of a composite resin, silver amalgam and cavit. J Endod. 1988;14:236-8.
31. Wennberg A, Hasselgren A. Cytotoxicity evaluation of temporary filling material. Int Endod J. 1981;14:121-4.
32. Callis PD, Santini A. Tissue response to retrograde root fillings in the ferret canine: A comparison of glass ionomer cement and gutta percha with sealer. Oral Surg. Oral Med Oral Pathol. 1987;64:475-9.
33. Lehtinen R. Tissue reaction of a glassionomer cement in the rat: a possible material for apicectomy using retrograde filling. Int J Oral Surg. 1985;14:105.
34. MacNeil K, Beatty R. Ketac silver and Fuji II as reverse fillings: a dye study Dent Res 1987;66:297
35. Chong BS, Pittford TR, Watson TF. The application and sealing ability of light-cured glass ionomer retrograde fillings. Int Endod J. 1991;24:223-32.
36. Youngson CC, Gly Jones J, Grieve AR. Marginal leakage associated with three posterior resin materials. J Dent Res. 1987;66:898.
37. Ferracane JL, Condon JR, Rate of elution of leachable components from composite, Dental Materials, (6), 1990, 282-7.
38. Geurtsen W, Substances released from dental resin composites and glass ionomer cements, European Journal of Oral Sciences, (106), 1998, 687-95.
39. John W.Nicholson, Polyacid-modified composite resins (compomers) and their use in clinical dentistry, Academy of dental materials, 2006, 968.
40. Rud J, Munksgaard EC, Andreasen JO, Rud V, Asmussen E. Retro grade filling with a composite and a dentin bonding agent. 1. Endont Dent Traumatol. 1991;7(3):118-25.
41. Rud J, Rud V. Long-term evaluation of retrograde root filling with dentin-bonded resin composite. J Endod. 1996;22:90-3
42. Luomanen M, Tuompo H, Study of titanium screws as retrograde fillings using bacteria and dye, Scandinavian journal of dental research.
43. Kodohiro G, A comparative of the sealing quality of zinc-free amalgam and Diaket when used as a retrograde filling material, Hawaii Dental Journal (15), 1984, 8-9.
44. Witherspoon DE, Gutmann JL, Analysis of the healing response to gutta-percha and Diaket when used as root-end filling materials in periradicular surgery, International Endodontic Journal, (33), 2000, 37-45.
45. Mitchell, David F:The Irritational Qualities of Dental materials. J Am Dent Assoc 1959; 59: 954.
46. Goel BR, Satish C, Suresh C, Goel S : Clinical evaluation of gold foil as an apical sealing material for reimplantation. Oral Surg Oral Med Oral Pathol. 1983; 55:514-518.
47. Bhargava S, Chandra S, Chandra S : A comparison of tissue reactions to potential retrograde root filling materials. Endodontology 1999; 11: 8-13.
48. Ingle JI, Bakland LK : Endodontics. 4th ed, Malvern USA, Williams & Wilkins, pp 728-731,1994.
49. Mangin C, Yesilsoy C, Nissan R, Stevens R : The comparative sealing ability of Hydroxyapatite cement, Mineral Trioxide Aggregate, and Super Ethoxybenzoic Acid as root-end filling material. J Endod. 2003; 29: 261- 264.
50. Brown WE, and Chow LC : A new calcium phosphate setting cement. J Dent Res. 1983; 62: 672 Abstr # 207.
51. Asgary S, Parirokh M, Eghbal MF, Brink F. Chemical differences between white and gray mineral trioxide aggregate. J Endod. 2005, 31(2): 101-103.
52. Torabinejad M, Hong CU, McDonald F, Pitt Ford TR. Physical and chemical properties of a new root- end filling material. J Endod. 1995:21:349-353.
53. Fischer E, Arens D, Miller C. Bacterial leakage of mineral trioxide aggregate as compared with zinc- free amalgam, intermediate restorative material and Super-EBA as a root-end filling material J En- dod. 1998; 24:176-179.
54. Apaydin ES, Shabahang S, Torabinejad M. Hard- tissue healing after application of fresh or set MTA as root-end-filling material. J Endod. 2004;30:21-24.
55. Lindeboom JA, Joost WFH, Frans K, Akker H A. comparative prospective randomized clinical study of MTA and IRM as root-end filling materials in single-rooted teeth in endodontic surgery. Oral Surg Oral Med Oral Pathol. 2005;100:495-500.
56. Gondim E, Zaia AA, Gomes BPFA, Ferraz CCR, Teixeira FB, Souza-Filho FJ. Investigation of the marginal adaption of root-end filling materials in root-end cavities prepared with ultrasonic tips. Int Endod J. 2003;36:491-499.
57. Torabinejad M, Hong CU, Lee SJ, Monsef M, Pitt Ford TR. Investigation of mineral trioxide aggregate for root-end filling in dogs. J Endod. 1995;21:606-8.
58. Torabinejad M, Wilder Smith P, Pitt Ford TR. Comparative investigation of marginal adaptation of mineral trioxide aggregate and other commonly used root end filling materials. J Endod. 1995;21:295-99.
59. Economides N, Pantelidou O, Kokkas A, Tziafas D. Short-term periradicular tissue response to mineral trioxide aggregate (MTA) as root-end filling material. Int Endod J. 2003;36:44-48.
60. Giovana et al. Sealing ability of castor oil polymer as root end filling material. Journal of Applied Oral Science. 2009; 17(3):220-3.
61. Choo-Ryung Chung, Euiseong Kim, Su-Jung Shin, Biocompatibility of bioaggregate cement on human pulp and periodontal ligament derived cells, Journal of Korean academy of conservative dentistry, 35(6), 2010, 473-478.
62. Yusuf-Burak Batur, Gozde Acar, Yagmur Yalcin, Seckin Dindar, Hande Sancakli, Ugur Erdemir, The cytotoxic evaluation of mineral trioxide aggregate and bioaggregate in the subcutaneous connective tissue of rats, Medical oral Pathology Oral Cir Bucal, 18(4), 2013, 745-751.
63. El Sayed MA, Saeed MH. In vitro comparative study of sealing ability of Diadent Bioaggregate and other root-end filling materials, Journal of conservative dentistry, 15(3), 2012, 249-252.
64. Zhenglin Yuan, Bin Peng, Han Jiang, Zhuan Bian, Ping Yan, Effect of Bioaggregate on Mineral-associated Gene Expression in Osteoblast cells, Journal of Endodontology, 36(7), 2010.
65. Trond Bjorvik Osen, Ina Iselin Astrup, Carl Haavard Knutsson, Biodentine as a root-end filling, 2012.
66. 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, 91(5), 2012, 454-459.
67. Camilleri J, Sorrentino F, Damidot D, Investigation of the hydration and bioactivity of radiopacified tricalcium silicate cement, Biodentine and MTA Angelus, Academy of Dent materials, 29(5), 2013, 580-593.
68. Tulsi Sanghavi, Nimisha Shah, Ruchi Rani Shah, Comparative analysis of sealing ability of Biodentine and Calcium phosphate cement against MTA as a furcal repair material, National journal of integrated research in medicine, 4(3), 2013, 56-60.
69. 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.
70. AS, Jeong SY, Lohan D, Elizabeth A, Chemically bonded phosphor-silicate ceramic, U.S.Patent & Trademark office, 2006.
71. 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, International endodontic journal, 44, 2011, 662-668.
72. 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, Journal of endodontology, 33(12), 2007, 1438-1443.
73. 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, International Endodontic Journal, 45, 2012, 1127-1134.
74. 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, Journal of Endodontics, volume 38, Issue 4, pages 486-489, April 2012.
75. De-Deus G, Canabarro A, Alves GG, Marins JR, Linhares AB, Granjeiro JM. Cytocompatibility of the ready-to-use bioceramic putty repair cement iRoot BP Plus with primary human osteoblasts. Int Endod J.; **45**: 508–513 (2012).
76. Porter ML, Bertó A, Primus CM, Watanabe I. Physical and chemical properties of new-generation endodontic materials. J Endod.; **36**: 524–528 (2010).
77. Lee SJ, Chung J, Na HS, Park EJ, Jeon HJ, Kim HC. Characteristics of novel root-end filling material using epoxy resin and Portland cement. Clin Oral Investig. **17**:1009–1015 (2013).
78. Aguilar FG, Roberti Garcia LF, Panzeri Pires-de-Souza FC. Biocompatibility of new calcium aluminate cement (EndoBinder). J Endod. 2012, 38(3): 367-371.
79. Maria G. Gandolfi, PhD, Salvatore Sauro, DDS,Francesco Mannocci, MD, DDS, PhD, Timothy F. Watson, BSc, BDS, PhD, FDS, Silvano Zanna, PharmD, Michela Capoferri, PharmD, Carlo Prati, MD, DDS, PhD, and Romano Mongiorgi, MS. New Tetrasilicate Cements as Retrograde Filling Material: An In Vitro Study on Fluid Penetration. J Endod; **33**(6): 742-745 (2007).