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MICRO-ENDODONTIC SURGERY PART 2: ROOT-END FILLING MATERIALS – A LITERATURE REVIEW

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ABSTRACT

The evolution of traditional techniques toward modern endodontic surgical procedures was discussed in Part 1 of this series. The clinical procedures usually comprise exposure of the involved area, root-end resection and preparation and placement of root-end filling material. This article is a review of the literature which has been published on those materials that have been suggested for clinical use as root end fillers and on the shift towards the current materials of choice.

INTRODUCTION

Endodontic surgery is considered when the peri-radicular disease process persists in an endodontically treated tooth and when retreatment has been unsuccessful or is not feasible.[1] The sequence of procedures involved in periapical endodontic surgery includes reflection of a full-thickness flap, gaining access to the root apex via an osteotomy, root-end resection, root-end cavity preparation, and sealing off the root canal system with a root-end filling.[2]

The purpose of root-end filling material is to provide a hermetic physical seal, and in this way to prevent the egress of micro-organisms or their by-products from the root canal system into the peri-radicular tissues.[3] Peri-radicular curettage alone, without root-end filling, eliminates only the effect of the leakage from the root canal system into the surrounding tissues. The curettage does not eliminate the cause of leakage, however, as most periapical lesions are the result of a leaking apical seal.[4] In order to ensure that healing does not regress, the root canal system should be resealed with an appropriate root-end filling.

It has been argued that a root-end filling might not be necessary should the existing root canal obturation appear well condensed radiographically.[5] However, the two-dimensional radiographic appearance of white lines representing obturation might not indicate the presence of voids and cannot exclude the presence of micro-organisms within the root canal system.[6,7] It is therefore mandatory to use a retrograde filling at the time of endodontic surgery.[8] Harty, Parkins and Wengraf (1970) concluded in a retrospective study of 1016 apicoectomy cases that the most important factor in achieving successful surgical endodontics was the apical seal.[9]

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ACRONYMS

BisGMA: bisphenol-A-glycidyl methacrylate
EBA: ethoxy benzoic acid
MTA: mineral trioxide aggregate
TEGDMA: triethylglycol dimethacrylate
UDMAm: urethane dimethacrylate

PROPERTIES OF AN IDEAL ROOT-END FILLING MATERIAL

The ideal root-end filling material should be:[3,10,11]

1. capable of preventing the leakage of bacteria and their by-products by adhering to the dentine walls and sealing the root end three-dimensionally
2. non-toxic
3. non-genotoxic
4. non-carcinogenic
5. biocompatible with host tissues and not a cause of any inflammatory reaction
6. insoluble in tissue fluids
7. dimensionally stable
8. unaffected by moisture during setting and when set
9. radiopaque
10. able to inhibit or not to promote the growth of micro-organisms
11. able to stimulate the regeneration of the periodontium, especially cementogenesis directly over the root-end filling
12. non-corrosive and not electrochemically active
13. non-staining to the tooth or periapical tissues
14. easy to use with a long shelf life.

ROOT-END FILLING MATERIALS

Various materials have been suggested and tested for use as root-end filling materials in the quest for a suitable product that fulfils all the ideal requirements.

1. Amalgam

Farrar has been credited with first using amalgam as a root-end filling material in 1884.[12] Since then amalgam has been the most widely used retrograde filling material and has served as a standard to which other materials are compared.[13]

The advantages of amalgam are that it is inexpensive, readily available, easy to manipulate, has good radiopacity and is insoluble in tissue fluids.[3,12] Its disadvantages as a root-end filling material include: initial microleakage,[14] electro-chemical corrosion,[15] induction of inflammation of adjacent peri-radicular tissues,[16] amalgam tattoo formation,[17] the need for an undercut in cavity preparation,[13] zinc toxicity,[18] delayed expansion,[19] and concerns over the introduction of mercury into the peri-radicular tissues.[3]

In 1991, Friedman identified amalgam as the material of choice for retrograde filling.[13] However, newer materials have since been developed to challenge the use of amalgam. According to Chong and Pitt Ford (2005), the use of amalgam as a root-end filling should now be confined to history.[3]

2. Gutta-Percha

Gutta-percha is derived from the sap of trees mostly of the genus *Palaquium* and in particular from the *palaquium gutta*.[20] Gutta-percha was introduced by Bowman in 1867 to fill the root canal space.[21] Gutta-percha for endodontic use contains 20% gutta-percha as a matrix, 66% zinc oxide as a filler, 11% heavy metal sulphates as radiopacifiers and 3% waxes or resins as a plasticiser.[22]

Gutta-percha is the most commonly used material to seal the root canal system during non-surgical endodontic treatment. When condensed, gutta-percha undergoes compaction and not compression. As a result there is no molecular spring-back to aid in the seal between the dentine-gutta-percha interface, which makes it necessary to use an endodontic sealer as a luting agent between dentine and gutta-percha.[23] Both heat-sealed- and thermoplastic gutta-percha used without sealer have displayed clinically unacceptable levels of leakage when tested as retrograde fillings,[24,25] whilst an endodontic sealer will reduce that leakage.[26] Cold burnishing of gutta-percha at the time of root-end resection has been a proposed technique for sealing the root-end, However, evidence shows that this technique results in significantly more leakage than amalgam and IRM.[25,27,28] The use of gutta-percha alone as a root-end filling cannot be advocated because of its poor sealing ability.

3. Cavit (3M ESPE, St Paul, Minnesota, USA)

Cavit is a calcium-sulphate-based temporary restorative material and is available in a premixed state that is simple to manipulate and to apply to a root-end cavity.[13] It is a hygroscopic material that undergoes linear expansion and sets when permeated with water, resulting in good marginal adaptation provided that a minimum thickness of 3,5mm of the material is placed.[13,29,30] However, Cavit is soluble and disintegrates when in contact with tissue fluids. For this reason, it cannot be recommended as a root-end filling.[31]

4. Glass-ionomer Cements

Conventional glass-ionomer cement was introduced in 1972 as a restorative material.[32] It is formed by a reaction between fluoro-aluminosilicate glass particles and an aqueous solution of polyalkanoic acid such as polyacrylic acid.[32]

The advantage of glass-ionomer cements is that they are able to form a chemical bond to dentine and provide a superior seal in this way.[13] Initially, they cause an intense inflammatory reaction that subsides completely.[3] Glass-ionomers are slow setting, difficult to handle and the setting reaction is adversely affected by moisture.[12,13] Silver released from the metal-reinforced glass-ionomer can cause discolouration and the corrosion products are toxic.[3] The resin-modified glass-ionomer such as Vitrebond (3M ESPE) has better handling properties and the setting reaction can be controlled by light-curing.[12] As it is not possible to ensure that the surgical site will be moisture free during the setting reaction, glass-ionomer cements cannot be recommended as ideal root-end fillings.

5. Reinforced Zinc-Oxide Eugenol Cements

In 1962, Nichols wrote of a preference for zinc-oxide eugenol as a retrograde filling because of its good handling properties and satisfactory postoperative results.[33] However, early zinc-oxide eugenol cements were weak, had a long setting time and were soluble.[3] Two modifications of zinc-oxide eugenol cement have been recommended as root-end fillings. These are described under (a) and (b) below.

a) **IRM** (Dentsply Sirona, York, Pennsylvania, USA)
In IRM, 20% by weight poly-methyl methacrylate has been added to the zinc-oxide powder and the eugenol liquid remains unaltered.[3]

b) **Super EBA cements**
   a. Stailine Super EBA (Staident International, Staines, Middlesex, UK) is the original Super EBA cement which has been developed.[34] The powder consists of 60% zinc-oxide, 34% silicon dioxide and 6% natural resin. The liquid comprises 62.5% ortho-ethoxy benzoic acid (EBA) and 37.5% eugenol.[34]
   b. Super EBA (Harry J. Bosworth Co., Skokie, Illinois, USA). In the powder component of this version of the cement, the silicon dioxide is replaced with 34% Alumina, but the liquid component is exactly the same as the Stailine Super EBA.[34]

Super EBA was first suggested as a retrograde filling in 1970.[35] Oynick and Oynick (1978) recommended the use of Super EBA as a root-end filling, as it is easy to manipulate and place as a result of its plasticity, adheres to the dentinal walls in moist conditions, has an adequate mixing time and sets quickly once in contact with tissues.[36] Super EBA has the ability to bond to itself unlike IRM and can, therefore, be placed incrementally.[31] Under Scanning Electron Microscope, Super EBA displayed good marginal adaptation and collagen fibres were observed growing over the material and in cracks within it.[36] Compared with traditional zinc-oxide eugenol cements, Super EBA has a high compressive strength, high tensile strength, neutral pH and low solubility.[37] A solubility study by Poggio et al. (2007) proved that both Super EBA and IRM were minimally soluble in water after 24 hours and also at two months.[38]

Eugenol is believed to be the major cytotoxic component of zinc-oxide eugenol cements, as free eugenol trapped in the set mass of zinc eugenolate is released by hydrolysis of the cement surface.[39] The modified reinforced ZOE cements can resist dissolution, which reduces the release of eugenol. The eugenol in IRM might have an affinity for the polymethylmethacrylate and this may limit the release of eugenol.[39] Both IRM and Super EBA exhibit cytotoxicity when freshly mixed; however, this is rapidly diminished as the cements set.[3] In a histological study of root-end fillings in dogs, Trope et al. (1996) confirmed the excellent tissue response to Super EBA and IRM, with EBA performing better than IRM but not to a statistically significant extent.[40] A cytotoxicity study by Al-Sa'eed, Al-Hiyasat and Darmani (2008) showed that super EBA was more cytotoxic than IRM, even though more eugenol is released from the latter.[41] It was concluded, therefore, that the zinc released from zinc-oxide eugenol cements is the major toxic element in zinc-oxide eugenol cements.[41] Zinc toxicity when released from amalgam has been reported previously.[42]

Super EBA and IRM displayed excellent sealing ability when compared with amalgam, gutta-percha and glass ionomer cement, with Super EBA displaying a superior seal to IRM.[27,43-46] On the basis of this evidence Super EBA and IRM can be recommended as root-end filling materials.

6. Composite Resin Materials

Composite resins are composed of aromatic or aliphatic dimethacrylate monomers, such as bisphenol-A-glycidyl methacrylate (BisGMA), triethylglycol dimethacrylate (TEGDMA) and urethane dimethacrylate(UDMA).[3]

Retroplast (Retroplast Trading, Rønne, Denmark) is a chemically cured flowable resin composite comprising BisGMA and TEGDMA.[3,47] A technique using Retroplast bonded with the dentine bonding agent GLUMA (Heraus Kulzer, Werheim, Germany) was introduced as a root-end filling in 1984.[47] The advantage of using GLUMA instead of other bonding agents is that it contains glutaraldehyde, which provides a disinfecting ability.[48]

The benefit of using this technique is that the traditional cylindrical root-end cavity preparation is not required, which can be particularly advantageous in difficult-to-access roots, such as in mandibular molars.[48] The advocated cavity design is shallow, concave and saucer shaped, with a cavosurface angle close to 180 degrees.[47] This preparation design allows for a reduced volume of composite against the dentine surface and prevents contraction gaps forming between dentine and composite during polymerisation.[48] EDTA is used to remove the smear layer after preparation of the root-end prior to the application of Gluma.[49]

An in-vitro study on apical dye leakage demonstrated that composite with a dentine bonding agent showed the least leakage when compared with amalgam, Cavit and gutta-percha.[50] In a long-term follow-up study of Retroplast-Gluma bonded retrograde fillings, 32 out of 33 cases maintained complete bone healing when evaluated between 8 and 9 years postoperatively.[47] The regeneration of alveolar bone, periodontal ligament fibres and cementum over composite-bonded retrograde fillings has been reported in case studies involving both monkeys and humans.[51]

The use of bonded composite as a root-end filling is technique sensitive and dependent on the maintenance of a completely dry field during placement.[3] In cases where haemostasis was unsuccessful, healing was incomplete probably as a result of bond failure between composite and dentine.[49]

7. Compomer Materials

Compomers are polyacid-modified composite resins that have a glass-ionomer component.[3] The inflammatory response of compomer after four weeks was comparable to that of Super EBA when implanted in rat femurs, and bone healing was observed for both materials at 12 weeks.[52] A clinical study comparing compomer and glass-ionomer cement as root-end fillings showed that a significantly higher success rate was observed in the compomer group (89%) than in cases in the glass-ionomer group(44%).[53] An electrochemical study by Park et al. (2004) found that there was no significant difference between MTA, Super EBA and Dyract-flow compomer.[54]

8. Gold Foil

The first two reported uses of gold foil as a retrograde filling were by Schuster in 1913 and by Lyons in 1920.[31] Gold foil exhibits excellent marginal adaptation and biocompatibility.[55] Improvement of biting forces was recorded following intentional replantation, and the group in which gold foil was used as a root-end filling material was found to be superior to amalgam and polycarboxylate cement.[55] No significant difference was observed in bone healing when gold-leaf and amalgam were used as root-end fillings.[56] A moisture-free environment is however required for the placement of gold foil, making it impractical to use as a root-end filling.[31]

9. Diaket (3M ESPE, St Paul, Minnesota, USA)

Diaket is a polyvinyl resin that is formed between zinc oxide and diaketone, and was originally developed for use as a root canal sealer when used in the ratio 1:1 powder to liquid.[3,57] A thicker consistency made from two or three parts powder to one part liquid is recommended for use as a root-end filling.[57] Diaket has good radiopacity and a working time of more than 30 minutes.[3]

When tested as a retrograde filling, Diaket proved to have a superior sealing ability to that of amalgam and glass-ionomer cement, as well as to IRM and EBA.[58,59] Gerhards and Wagner (1996) found Diaket to have a similar sealing ability to amalgam and an inferior sealing ability compared with glass ionomer cement.[60]

Nencka, Walia and Austin (1995) reported excellent handling characteristics and biocompatibility of Diaket when implanted in rat bone.[61] Complete regeneration of the periodontium was observed when MTA and Diaket were used as retrograde fillings in dogs and Diaket was reported to have superior handling properties over MTA.[57] A histological evaluation of the tissue response to Diaket showed a hard-tissue matrix with periodontal ligament and cementum formation over the material, indicating that it is a bio-inductive material.[62] Diaket compared with gutta-percha displayed a better healing response with bone formation, periodontal ligament regeneration and cementum formation.[63]

10. Polycarboxylate Cement

Zinc polycarboxylate cement was introduced in 1968 by Dr Dennis Smith and is made up of powder and liquid components that harden when mixed, via an acid/base reaction.[64] The powder comprises modified zinc-oxide with fillers and the liquid is an aqueous solution of polyacrylic acid.[64] Polycarboxylate cement has a strong bond with enamel and a far weaker bond with dentine, as a result of a chelation reaction between the carboxyl groups of the cement and the calcium in tooth structure.[64] Polycarboxylate cement is used as a luting cement and restorative material. Owing to its low water solubility, it was considered as a root-end filling material.[13] In a dye-penetration study, Barry et al. (1976) showed that polycarboxylate cement leaked significantly more than did amalgam when used as root-end fillings.[65] Owing to its viscosity and accelerated setting time in a warm environment, application as root-end filling is difficult.[13] The demanding handling properties and poor sealing ability as a root-end filling render polycarboxylate cements unsuitable for this purpose.

11. Bioceramic Cements

Bioceramic materials could be described as biocompatible ceramics that are appropriate for use in the human body.[66] The first bioceramic cement patented for use as a root-end filling was ProRoot MTA (Dentsply Sirona), and is commonly referred to as Mineral Trioxide Aggregate (MTA).[67] MTA was developed for use as a root-end filling material at Loma Linda University by Professor Mahmoud Torabinejad and colleagues in the early 1990s.[68] The first description of MTA in the scientific literature was in 1993 and by 1998 the U.S Food and Drug Administration had approved MTAs for endodontic treatment.[68,69]

MTA is a fine hydrophilic powder derived from a Portland cement parent compound.[68] Portland cement is a basic ingredient of concrete used in the construction industry, and was first used as a root canal filling in 1878 by Witte.[70,71] Bismuth is a heavy metal and is added to the cement in the form of Bismuth oxide (Bi_2O_3) in the ratio of 4:1 to provide radio-opacity to MTA for radiological diagnosis.[72] MTA cement is prepared by mixing its powder with sterile water using a 3:1 powder-to-liquid ratio.[11] Upon hydration, calcium hydroxide and a calcium silicate hydrate gel are formed, which solidify into a hard structure in approximately 165 minutes.[11,72] The pH of MTA is 10.2 immediately after mixing and increases to 12.5 after three hours.[73] Grey ProRoot MTA was introduced to the market in 1998, and in 2002 white ProRoot MTA became available.[74] An electron probe microanalysis revealed that white MTA has less iron, aluminium and magnesium than Grey MTA.[75] The development of white MTA was intended to address the cosmetic concerns raised by the potential of grey MTA to discolour the dentine.[76]

MTA can be described as a hydraulic cement because it is primarily dependent on hydration reactions for its setting.[77] This contrasts with the usual acid-base reactions of other dental materials.[77] The main constituent of MTA is calcium silicate.[78] MTA can therefore be described as a hydraulic calcium silicate cement (HCSC).[79]

The advantages of MTA as a root-end filling are:

1. MTA has the ability to set in a moist environment, including blood.[11]
2. The excellent sealing ability of MTA has been well established by numerous studies on microleakage and marginal adaptation.[80]
3. MTA is biocompatible with human tissues and was shown to be one of the least cytotoxic materials in various studies on cell culture.[80]
4. MTA is a bioactive material, as is evidenced by the formation of hydroxyapatite crystals on its surface when it comes into contact with a physiologic solution.[74,81,82] MTA releases calcium ions that react with extrinsic phosphate ions in the surrounding environment in order to form hydroxyapatite.[83] The formation of hydroxyapatite on the surface of MTA enhances the chemical bond between MTA and dentine and can promote the remineralisation of the surrounding hard tissues.[81]
5. Osteoconductive: MTA and Super EBA were found to be osteoconductive, as they stimulated osteogenesis when implanted in bone.[84] The promotion of osteoblastic activity by MTA in bone has been well established.[85,86,87]
6. Stimulates cementogenesis: A histological study performed on beagle dogs by Torabinejad et al. (1995) showed that when MTA and amalgam were used as root-end fillings, cementum formed directly over MTA, whereas no cementum formed over amalgam.[88] In a similar histological study carried out on monkeys and in which MTA and amalgam were used as root-end fillings, a thick layer of cementum was found over the MTA that continued over the resected dentine and joined the cementum on the side of the root.[89] The combination of the physical bond that MTA forms with dentine and the regeneration of cementum results in the formation of a double seal.[57]
7. Anti-bacterial: The release of calcium hydroxide upon the hydration creates a highly alkaline environment which is antibacterial.[90]

The drawbacks of MTA include:[90,91]

1. Long setting time
2. Potential to cause tooth discolouration
3. Presence of toxic elements within the material
4. Difficult handling properties
5. Expensive to purchase
6. No known solvent
7. Difficult to remove once set
8. Washout in the early stages of placement

Several versions of hydraulic calcium silicate cements for endodontic use have emerged since the introduction of the ProRoot MTA material. Some of the materials that have addressed the limitations of the pioneer material include those set out in the paragraphs that follow (a to e)

a. MTA Angelus (Angelus, Londrina, Parana, Brazil)

MTA Angelus comprises 80% Portland cement and 20% bismuth oxide for radiopacity. Calcium sulphate has been excluded from the manufacture process of MTA Angelus so as to reduce its setting time to approximately 14 minutes.[66]

b. MTA Plus™ (Prevest Denpro Limited, Jamu, India)

MTA Plus™ is a novel mineral trioxide aggregate material that has a finer particle size than MTA.[92] The MTA Plus™ powder is supplied with a proprietary salt-free polymer gel and water, either one of which can be used as mixing vehicles.[71] The finer particle size improves the handling and placement of MTA Plus™, and the purpose of the gel is to provide an anti-washout property to the material.[71,93]

The setting time of MTA Plus™ mixed with water (180 mins) was found to be longer than for MTA Plus™ mixed with the anti-washout gel by 65 minutes.[95]

It is necessary to irrigate the osteotomy site prior to closing a periapical flap to avoid complications.[93] One of the drawbacks of MTA is washout, which can be defined as the tendency of a cement to disintegrate upon early contact with blood and other fluids.[94] Washout resistance is an important quality of a root-end filling, as the final irrigation and resuming of blood flow to the area might result in the loss of some of the material placed in the root-end cavity and the compromising of the apical seal in the process of loss.[95]

During the construction of underwater structures a water-soluble polymer is added to concrete in order to modify its rheological properties and make it resistant to washout.[94] Resistance to washout is achieved by increasing the viscosity of the liquid used to mix the cement powder, which increases the resistance of the cement to segregation by an external washing action.[95] A similar concept was employed in the development of the gel additive to MTA PlusTM.[95]

c. Biodentine™ (Septodont, Saint-Maur-des Fosses, France)

Biodentine™ is a synthetic tricalcium-silicate-based cement that is advertised as a 'bioactive dentine substitute'.[96] The production of Biodentine™ is based on 'Active Biosilicate Technology™', which results in a pure tricalcium silicate that is free of metallic impurities.[97]

Biodentine™ has a powder component in a capsule and liquid packaged in a pipette. The powder is made up of tricalcium silicate (main core material), dicalcium silicate (second core material), calcium carbonate and calcium oxide (filler materials), iron oxide (colouring agent) and zirconium oxide (radiopacifier).[98] The liquid consists of a hydrosoluble polymer (water-reducing agent) and calcium chloride(setting accelerator).[97] The hydrosoluble polymer can also be described as a superplasticizer and maintains the flowability of the mixture in a low water-to-solid ratio.[99] The advantage of synthesising pure tricalcium silicate compared with purifying natural tricalcium silicate is that the mineralogy is not altered by sintering conditions or variable composition of raw materials.[99] The absence of metallic impurities has been confirmed by the analysis of acid extracts and leached trace elements of Biodentine™.[100] The particle size of the Biodentine™ powder was found to be much finer than that of MTA.[99]

The aqueous solution is mixed with the powder within the capsule in a triturator for 30 seconds at a speed of 4000-4200 rotations per minute.[97] The hydration reaction results in the formation of a calcium silicate hydrate gel and the release of calcium hydroxide.[101] According to Camilleri, Sorrentino and Damidot (2013), the calcium carbonate acts a nucleation site for the calcium silicate hydrate; as a result there is a shorter induction period and therefore an initial set within 12 minutes.[99] The final setting time of BiodentineTM was found to be 45 minutes.[100]

d. MTA Flow (Ultradent Products Inc., Utah, USA)

MTA Flow is a mineral trioxide aggregate repair cement that comprises a powder constituted of ultrafine-grained tricalcium and dicalcium silicate powder, and a proprietary water-based gel.[102] The powder gel formulation is smooth because of the small particle size of less than 10 microns of MTA Flow powder. The formulation is also resistant to washout as a result of the gel formulation.[102] MTA Flow, like other calcium silicate cements, is indicated for root-end filling, pulp capping, pulpotomies, apexification, root resorption and perforation repair.[102] The mixing ratio of MTA Flow is adaptable according to the consistency required for the specific procedure, which may range from thin, thick to putty.[102] A putty consistency is mixed for root-end filling purposes. An added advantage of this product is that it is placed into a Skini syringe after mixing, which allows it to be accurately expressed from the Black Micro® Tip (22 gauge) when used for pulp capping and perforation repairs, or a NaviTip® Tip (29 gauge) for resorption repairs, apexification, or placement of an apical plug to the desired site.[102] The working time of MTA Flow is 15 minutes, and it may be rinsed or air dried after 5 minutes without risk of it being dislodged.[102]

e. Calcium Phosphate Silicate Cements

The latest generation of bioceramic cements is a Calcium Phosphate Silicate Cement (CPSC) that has phosphate salts added to the conventional calcium silicate cements.[79] The main components of CPSCs are calcium silicates, zirconium oxide, tantalum oxide and calcium phosphate monobasic.[66] The addition of phosphate salts is intended to enhance the mechanical properties and biocompatibility of the cement. Examples of CPSCs are: EndoSequence Root Repair Material Putty (ERRM Putty; Brasseler USA, Savannah, GA, USA), EndoSequence Root Repair Material Paste (ERRM Paste; Brasseler USA), iRoot BioAggregate (Innovative Bioceramix, Vancouver, Canada) and TotalFill® BC RRM™ Putty (FKG, La Chaux-de-Fonds, Switzerland). The materials are available either as a premixed mouldable putty or as a paste in a syringe with delivery tips for intra-canal delivery and the material begins to set when in contact with moisture.[66]

CONCLUSION

The root-end filling material of choice during the 19th century and most of the 20th century was amalgam. The reinforced ZOE materials, IRM and Super EBA were on the verge of superseding amalgam as the preferred root-end filling material toward the end of the 20th century. Calcium silicate cement MTA introduced at the turn of the century outclassed all materials previously tested because of its ability to appreciate moisture, its excellent sealing ability, and its bioactivity and biocompatibility. The continuous evolution of calcium silicate materials has resulted in products with improved handling properties and has provided the endodontic field with appropriate and effective repair- and root-end filling materials.

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