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## **Bioceramic root canal sealers: A review**

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**Abstract**--The role of root canal sealers is to close cavities in the canal and open accessory canals and multiple holes, create a connection between the canal wall and the surface of the filling material, and act as plasticizers for core fillings. The sealers are grouped according to their main chemical components: seals based on zinc oxide eugenol, caoh, gic, silicone, resin and bioceramics bioactive materials such as glass and calcium phosphate combine with the surrounding tissue to stimulate the growth of more robust tissue. Bioinert materials like zirconia and alumina has no effects on the adjacent tissues.

**Keywords**--bioceramic, root, canal sealers, zinc oxide eugenol.

**Introduction**

The role of root canal sealers is to close cavities in the canal and open accessory canals and multiple holes, create a connection between the canal wall and the surface of the filling material, and act as plasticizers for core fillings. The sealers are grouped according to their main chemical components: seals based on zinc oxide eugenol, caoh,gic, silicone, resin and bioceramics bioactive materials such

as glass and calcium phosphate combine with the surrounding tissue to stimulate the growth of more robust tissue. Bioinert materials like zirconia and alumina has no effects on the adjacent tissues.<sup>[1,2,3,4,5]</sup>. The first commercially available sealer based on calcium silicate is mineral trioxide aggregate (MTA) fillapex, which consists of 13 percent mta and salicylate resin. Studies have shown deeper penetration and good sealing ability and advantageous properties such as osteoinductivity, biocompatibility, which is suitable for use in endodontics.

According to current data, bioceramic root canal sealers have different toxic potentials at the cellular and tissue level. It was traditionally used to block the dentin tubules and create a homogeneous interface between the filling material and the dentin walls. Studies have shown that adequate bone healing occurs after adequate endodontic therapy, mainly due to the differentiation and contribution of osteoblasts. The latest generation of calcium and phosphate silicate based root canal sealers are the so-called premix bioceramics sealers (full fill, irootsp and endosequencebioceramics seals) , which do not require any manipulation of cement. these bioceramics sealers release more calcium hydroxide during setting, which corresponds to mtafillapex, which accounts for their high ph and antibacterial properties . Not only these, but their effect together with the gutta-percha tips, which are impregnated with bioceramic nanoparticles, ensure an intracanal restoration with null voids.

Additionally, bioceramic root canal sealers can promote physical and chemical bonding with dentin by creating hydroxyapatite precipitates at the dentin sealer bond during the set. Numerous studies have shown that root canal fillings emerged coronally in contact with oral flora. In vitro and in vivo studies showed penetration of dye and bacteria through filled canals within three months and bacterial endotoxin within 21 days. Conventional sealers have certain disadvantages in that they can shrink as they harden and dissolve in tissue fluids, creating a space that allows microbes to escape. the most important rule of endodontic treatment is the three-dimensional filling of the endodontic spaces, which are permanently separated from the content of the root canal by material components of irritation of the periapical tissue and reactions to cross infections. Due to the latest technology and limited scientific knowledge, the efficacy of bioceramic root canal sealers remains unclear.

### **Advantages**

- Excellent biocompatibility properties due to its similarity to biological hydroxyapatite.
- Intrinsic osteoinductive capacity due to its ability to absorb osteoinductive substances when an adjacent bone healing process is taking place.
- Its function as a regenerative scaffold made of resorbable grids that form a scaffold that eventually dissolves when tissue is rebuilt.
- Provides an perfect hermetic seal, and has radiopaque properties.

### **Mechanism of action**

MTA cures through an exothermic reaction that requires hydration of its powder to create the cement paste that sets over time. The bioactivity of MTA is attributed

to hydration of the powder, which leads to dissolution and diffusion of calcium ions and other reactions that lead to the formation of apatite. The accelerator of this reaction is calcium hydroxide and the retarder is sodium hypochlorite. The primary mechanism of the bioceramic root canal sealer in dentin is unclear, but the following mechanisms have been suggested for calcium silicate based sealers.

- Tubular diffusion of the sealer particles to create interlocking mechanical connections [65]
- Reaction of calcium and phosphate in the presence of dentin moisture, leading to the formation of apatite crystals together with the preformed mineral infiltration zone.[66]
- Infiltration of the mineral content of the sealer into the intertubular dentin, which leads to the formation of a zone of mineral infiltration, which after the process of denaturation of the fibers collagen with an alkali sealer[67]

### **Classification**

- Calcium silicate based root canal sealer
- MTA based sealer
- calcium phosphate sealer

### **Calcium silicate based root sealer**

The series prototype was introduced by Schroeder in 1957, with excellent sealing and physical properties. Several studies have shown that AH Plus is the gold standard for sealers due to its resistance to resorption and malleability. Although it has limitations such as possible mutagenicity, cytotoxicity and inflammatory response. Furthermore, its hydrophobicity prevents the hydrophilic channel from filling completely. [16,17,18]

### **Properties of calcium silicate based sealers**

#### **Sealing ability**

The sealability of calcium silicate sealers varies between studies due to different experimental methods and materials. In general, conventional epoxy-based sealers show similar or significantly less leakage than calcium silicate-based sealers. Calcium silicate sealers show a better seal 4 weeks after setting[22]. Another characteristic feature of this sealer is biomineralization. Calcium silicate creates label-like structures at the calcium silicate / dentin interface. The so-called mineral infiltration zone is a hybrid zone in which the recrystallization of hydroxyapatite occurs when calcium silicate is applied to the dentin. However, the zone of mineral infiltration has not been clearly shown to affect the result, as calcium ions react with carbon dioxide in the tissue to form calcite crystals. These crystals can reduce fringe spaces and porosity and increase cement retention. In contrast, in some studies, apatite deposition of calcium silicate-based sealers did not reduce leakage due to its porous shape[19,20,21]. Treatment with EDTA as a final rinse can increase the bond strength of epoxy-based sealers and reduce leakage. The use of NaOCl shows the correct sealability of calcium silicate based sealers [8,9].

### **Push out bond strength**

Push out bond strength is used to assess the interfacial adhesion between root canal sealer and root dentin<sup>[6]</sup>. Calcium silicate-based sealers have improved dislocation and durability by micro-mechanically bonding to dentin, reducing interface space. In general, they have less adhesive strength when pushed outward than resin-based stamps, which chemically bond to dentin<sup>[7]</sup>.

Heat can accelerate hydration and hydroxyapatite formation in calcium silicate sealers, showed lower bond strength with thermoplastic injection technique than with use of cold compaction. The residual water in the tubular opening can evaporate and affect hydration <sup>[22,23]</sup>.

### **Biocompatibility**

Calcium silicate sealers have shown greater cell viability than ah plus calcium silicate sealers are biocompatible while studies have shown that calcium silicate sealers are biocompatible and non-cytotoxic<sup>[22,26]</sup>. Loushine et al. Reported that the endo-sequence bc was cytotoxic to mouse osteoblast cells after 6 weeks. And it was reported that endoseal mta did not promote the growth of human gingival fibroblasts on its surface <sup>25]</sup>. The alkalinity of calcium silicate sealers is greater than ah plus. The highest ph values were observed in irootsp, endosealemcb and endo cpm, followed by mtafillapex and endoseal mta. <sup>[26]</sup>. Hydrophilicity reduces sealer contact angle and increases sealer penetration into dentin tubules. The agar diffusion test and the direct contact test were used to evaluate the antimicrobial properties of root canal sealers. The antimicrobial properties of calcium silicate sealers changes after set.

### **Antibacterial effect**

Most calcium silicate based sealers show an antibacterial effect against e. faecalis, causing secondary infection. Complete removal of microbes from the root canal system is not possible. With irootsp, all bacteria are killed immediately after contact, while with ah plus viable bacteria were significantly reduced and eradicated within 520 minutes. Biorootrcs shows stronger antibacterial effect than ah plus<sup>[1,27]</sup>

### **Bioactivity**

Calcium silicate based sealers, are considered bioactive materials because they induce the formation of hard tissue in both the perio related tissues. Calcium silicate sealers show results of enhancing osteoblastic marker gene expression and induce a greater amount of mineralization matrix than other types of sealer. The release of calcium from calcium silicate sealer occurs through osteoblastic differentiation and the formation of calcium nodules <sup>[28,29]</sup>

### **Solubility**

Solubility is the loss of mass of a material during immersion in water. The solubility of a sealer must not exceed three percent by mass per ansi / ada (2000) specification number 57<sup>[33,34]</sup> the solubility of irootsp and mtafillapex was high

(20.64% and 14.89%, respectively), which does not meet ansi / ada requirements. Compared to ah plus sealer, mtafillapex sealer have higher solubility and voids at the dentin / sealer interface. Study shows mta angelus also has low solubility due to an insoluble matrix of crystalline silica within itself that maintains its integrity even in the presence of water<sup>[35]</sup>. For both mta fillapex and ah plus, the solubility and water absorption increased significantly over time over a period of 1 to 28 days. Mtafillapex had a higher solubility than guttaflow.

Mtafillapex and ecandoquencebc sealer have a higher solubility than ah plus. The solubility of ah plus and mta angelus was in accordance with ansi / ada requirements, while irootsp, mtafillapex, and sealapex were different. Morphological changes were observed on the external and internal surfaces after solubility test in the sem / edx analysis of all sealants. According to iso 6786/2001, a root canal sealer must have a flow rate of not less than 20 mm. Mtafillapex had a flowability of more than 20mm and a film thickness of less than 50  $\mu\text{m}$ . Others indicated a similar course, similar film thickness, and lower compressive strength of mtafillapex compared to ah plus sealants. In addition, they were a similarity between mtafillapex and endosequencebc sealers. The film thickness of mtafillapex is greater than ah plus and endosequencebc sealer. The flow test showed that bc sealer and ah plus had a flow rate of 26.96 mm and 21.17 mm, respectively<sup>[30, 32]</sup>

### **Radiopacity**

Radiopacity, a well-known characteristic of endodontic sealers, must be present in any root canal filling material to some degree to assess the quality of root filling function. Two standard disc and tissue simulator methods were used to assess radiopacity in a study that showed it to be higher in ah plus than in mtafillapex and endo cpm. The radiopacity of the endo cpm sealer was 6 mm. The radiopacity of mtafillapex and ahplus was 3.9 and 18.4 mm, respectively, and the value of 10.8 and 4.3 for the radiopacity of the endosequencebc and mtafillapex sealers. However, another study showed that the radiopacity of endosequencebc sealer and ah plus was 3.84 and 6.90 mm, respectively <sup>[31,36,34]</sup>.

### **Retreatability**

Many newer root canal sealers are available on the market; the recently introduced biorootrcs is a two-component system based on tricalcium silicate<sup>[68]</sup>. The sealing effect of biorootrcs is comparable to ah plus sealers, micro-ct studies have shown that this could be due to the lower flow rate and processing time than ah plus. Energy scattering x-ray spectroscopic analysis showed that biorootrcs contains carbon, calcium, oxygen, zirconium, chlorine, silicon and no added toxic elements or heavy metals<sup>[68]</sup>. A study demonstrated the ability of rcbioroot to penetrate dentin tubules and, compared to conventional root canal sealers, determined by confocal microscopy <sup>[38]</sup>. The microct analysis showed that the bioroot-rcs in the apical third part of the canal had more volume of sealer residues than mtafillapex sealer and followed by diaproseal sealer. This shows that the apical curvature of a root canal minimizes post-treatment instrument contact on all root canal walls <sup>[39]</sup>. the biorootrcs has a "its rock-like consistency" compared to mtafillapex and diaproseal sealer which makes it difficult to

remove. bio root ccs are larger than mta fillapex sealer, showed less sealing residue in the root canal, and prevented fewer cracks after post-treatment compared to bio root ccs.<sup>[40,41,42,43,44,68]</sup> .post-treatment crack formation is due to expansion and increased resilience of the areas surrounding the crack. When the tear opens, the collagen filaments stretch over it and distribute the energy through their deformation or friction. Increased mineral infiltration zone and mineral plugging of bio root root canal sealers may be the reason for crack growth resistance.<sup>[45,46]</sup> In bio root ccs, more volume of sealer remnants in the root canal and prevention of cracks after retreatment might be due to increased biomineralization activity of this material. <sup>[68]</sup>

### **MTA based sealers**

MTA is a material with a slow setting process that takes approximately 3 hours to initially set and the reaction slowly takes a week and possibly a month or more. Hydration of the powder results in a colloidal gel with a pH of 10.5 to 12.5. Mta is a biocompatible material with various clinical applications in root canal treatment. This material shows better improvement than other materials in endodontic procedures, including improved root, bone healing and antimicrobial activity. Examples of mta based sealers are endocpm sealer, mta obturation, prorooteendo sealer, mta fillapex. Mta fillapex is an mta-based sealer that was developed by angelus (londrina / paraná / brazil) dring 2010. Its pasty formula allows a perfect filling of the entire root canal. The composition of fillapex mta is more stable than calcium hydroxide, maintains the pH value as an antibacterial effect. Shows no color change of the tooth.

Mta-based root canal sealers for endodontic treatment have been developed to meet the criteria of a good sealer. Mta improves sealability due to expansion when used in a humid environment. Mta has also been shown to be superior in bacterial microleak tests that do not involve bacteria ingress between mta surfaces. In 2007, holland et al. Investigated the effect of filling rate on apical and periapical tissues after the root canal is filled with mta and showed good results. Direct contact of the sealer with the periapical tissue can lead to cell degeneration and delayed wound healing. Furthermore, clinical practice suggests that fluid and blood contamination in moist areas of the root and moist dentin can interfere with the sealing of hydrophobic concave root canal sealer and the effectiveness of adhesion on wet substrates. mta fillapex is a two component catalyst paste system. The base consists of silica, bismuth oxide, and salicylate resin components such as butylene glycol, rosin, and methyl salicylate. The catalyst consists of titanium dioxide, silicon dioxide, and base resin components such as toluenesulfonamide, rosinate, pentaerythritol and an mta content of 13.2% as filler<sup>[68]</sup>

### **Proroot endo sealer**

Cytotoxicity: The eluent derived from the sealer has comparatively mild toxic effects on the preosteoblast cells when compared with commercially available sealers under the testing conditions. There is also minimum inhibition of the osteogenic potential of the preosteoblast cells. Thus, it is minimally tissue irritant even when it is inadvertently extruded through the apical constriction.<sup>[47,48]</sup>

Pushout bond strength: The dislocation resistance of proroot was independent of location of radicular dentin and was more than ah plus and pulp canal sealer. This may be due to hardness of calcium silicate-based sealer after setting in 100% relative humidity. Microleakage studies of prorootmta sealer showed similar sealing ability to epoxy resin-based sealer superior to zinc oxide eugenol-based root canal sealers when evaluated using fluid filtration system.<sup>[48]</sup>

**Mtafillapex:** (angelus)

According to the manufacturer, its composition according consists essentially of mta, salicylate resin, natural resin, bismuth and silica. Mtafillapex is the first paste: mta-based salicylate resin root canal sealing paste, versatile for all filling methods. Delivers easily with no waste and has excellent handling properties with efficient set time. Half of mtafillapex paste - contains 13.2% mta. Known for its biocompatibility, mta creates an impressive airtight seal in which the mta particles expand and prevent microinfiltration. The other half of the fillapexmta paste: contains biologically compatible salicylate resin (1,3-butylene glycol disalicylate resin), which is non-tissue damaging and therefore a better choice than resins epoxy, which have been shown to have mutagenic effects . The two fillapexmta pastes are combined in a homogeneous mixture to form a rigid but semi-permeable structure in which excess mta is dispersed <sup>[51,52]</sup>

- flow: mtafillapex has a high flow rate (27 mm) and a small film thickness, so it easily penetrates the other accessory channels. Regardless of the sealing technique, mtafillapex confidently offers a high level of sealability that, unlike other seals, is not affected by heat. <sup>[49,50]</sup>
- ideal working time: 35 minutes.
- antibacterial properties: it has excellent antibacterial properties since the solubility is extremely low (0.1%), so it does not erode over time like the other sealers. In addition, it has a high ph value for a long-lasting antibacterial effect and tends to keep calcium release relatively constant for up to 14 days.
- mta's x-ray opacity exceeds recommended iso values, so x-ray diagnostics are never a question mark. And if follow-up treatment is required, it can be easily removed<sup>[53,54]</sup>

**Cpm sealers**

The powder presented as a white modified portland cement based material, its most significant difference is the presence of a large amount of calcium carbonate which is said to increase the release of calcium ions and provide good sealing properties, adhesion to the walls of dentin, adequate flow rate and non irritant . The addition of calcium carbonate reduces the ph value after adjustment from 12.5 to 10. In this way, surface necrosis in contact with the material is limited, allowing the action of alkaline phosphatase. Studies have shown that the addition of calcium chloride to mta shortens setting time, improves sealability, and facilitates insertion into cavities without compromising biocompatibility. When analyzing the endo cpm sealer for its sealability in apical plugs, it was found that there is no difference between the graymta angelus and the endo cpm sealer <sup>55,56</sup> .

### **Mtaobtura**

The development of mtaobtura aimed to achieve an endodontic sealer that combines the biological and sealing properties of mta. This seal showed very stable leakage values after 15 and 30 days, as expected for an mta-based material. Its performance replicated the good sealability of mta as a repair material. However, after 60 days, mtaobtura showed a significant increase in leakage. Bernardes et al. The study carried out by the mtaobtura showed the lowest flow rate (27.65 mm). Due to this property, mtaobtura is likely to be more difficult to penetrate into the ramifications and irregularities of the root canal walls than the other sealers tested.<sup>[54,57,58]</sup>

### **Mtas experimental sealer**

It consists of 80% white portland cement, zirconium oxide as a radiation protection agent, calcium chloride as an additive and a resin carrier. It is made using a 5: 3 powder to liquid ratio by weight determined in previous pilot studies. It has an initial and final setting time similar to ah plus sealer. According to a recent study, Mtas showed greater calcium release than mta and portland cement, except for a period of 14 days. This may be due to the inclusion of calcium chloride in the stamp. The ph of the mtas sealant was significantly higher up to 48 hours and was statistically similar to that of mta and portland cement. This indicates that mtas has a great capacity to release hydroxyl ions.<sup>[53]</sup>

### **F-doped mta cements**

Recently, fluorine-containing portland cement was shown to have significant expansion in water and in pbs. Expansion of portland-based cements is a water-dependent mechanism due to water absorption, as no expansion occurred when immersed in hexadecane oil. Furthermore, ettringite formation, responsible for expansion, is accelerated in fluorine-doped cements. Older sodium fluoride was included in the test cement. Fmta for its expansive properties and long setting time and its activity in the pulp cells of bones and teeth. <sup>(59)</sup>. Therefore, the fluoride-containing cement showed better sealability, probably due to higher expansion. In addition, fluoride ions from cementum can penetrate the dentin and increase the mineralization of the dentin and also clog and seal the dentin tubules. The cement setting reaction involves the continuous formation of hydration products, which contribute to the reduction of microchannels in the cement mass. Hydration products can react with dentin ions (ca and p) and reduce marginal spaces, improving the sealing of the apical third<sup>[60]</sup>. The large amount of portlandite that forms during hydration of tricalcium silicate causes the ph to rise early to 12, which can play a protective role in preventing recontamination of a filled root canal.<sup>(48)</sup>

### **Calcium phosphate sealers**

Calcium phosphate was manipulated by legeros et al. Used as a restorative bioceramic dental cement. However, the first documented use of bioceramics as root canal sealing took place two years later, when krell and wefel compared the efficacy of experimental calcium phosphate cement with grossman's seal in

extracted teeth and found no significant differences between the two. Two seals regarding apical occlusion, adaptation, occlusion of the dentinal tubules, adhesion, cohesion or morphological appearance<sup>[10]</sup> however, the experimental calcium phosphate sealer failed to seal apically as effectively as Grossman's sealer. Chohayeb et al. Later investigated the use of calcium phosphate as a root canal sealer in adult canine teeth. They reported that the calcium phosphate-based sealer provides a more uniform and closer fit to the dentin walls compared to gutta-percha.<sup>[11]</sup> Subsequently, calcium phosphate cement has been used successfully in endodontic treatments including pulp capping, apical barrier formation, repair of periapical defects, and repair of perforations.<sup>[12]</sup>

Most studies evaluate biocompatibility by studying cytotoxicity in relation to the effect of the material on cell survival. The cytotoxicity of the bioceramic-based stamps was examined in vitro using human and mouse osteoblast cells and human periodontal ligament cells. Calcium phosphate is also the main inorganic component of hard tissues (teeth and bones). Consequently, the literature suggests that many bioceramic sealers have the potential to promote bone regeneration if they are inadvertently extruded through the apical foramen during root canal filling or root perforation repair.<sup>[13,14]</sup> Capseali and capseal ii sealer cause less tissue irritation and inflammation compared to other sealers. Schon et al. Examined the effect of capseal i and capseal ii compared to Sankinapatit root sealer (type i and type iii) and a eugenol zinc oxide based sealer (pulp canal sealer). The researchers exposed human periodontal fibroblast cells to various sealer before measuring the inflammatory response using inflammatory mediators and the viability and osteogenic potential of MG63 osteoblast cells. They found that capseal i and capseal ii have low cytotoxicity and facilitate periapical dentoalveolar healing by regulating cellular mediators of periodontal ligament cells and osteoblast differentiation. Mtafillapex was found to have severe cytotoxic effects on fibroblast cells when freshly mixed.<sup>[62,63]</sup>

### **Setting time**

A slow set time can cause tissue irritation, and most root canal sealers produce some level of toxicity until fully set. The amount of moisture in the dentin tubules of the canal walls can be influenced by absorption with paper points, the presence of smear plugs or tubular sclerosis.<sup>[14]</sup> Author Loushine reported that the endosequencebc sealer setting reaction is a two phase reaction. In phase i, monobasic calcium phosphate reacts with calcium hydroxide in the presence of water to form water and hydroxyapatite. In phase ii, the water from the dentin moisture and the water generated by the reaction in phase i contribute to the hydration of the calcium silicate particles to trigger a calcium silicate hydrate phase, by the Gilmore needle method and showed 168 hours to fully set<sup>[14,15]</sup>

### **Bio compatibility**

The capseali and capseal ii groups showed less inflammation than the calcium phosphate based sealer. As mentioned, calcium phosphate cement is biocompatible, since calcium phosphate is the main inorganic component of hard tissue and the synthesized free calcium and phosphate ions can be used in metabolism. Also, the new stamps do not contain polyacrylic acid. A sodium

phosphate solution with the cpc was used as a replacement for the polyacrylic acid. Sodium phosphate is already known to show excellent tissue reactions. It has a ph of 7.4 and promotes the formation of hydroxyapatite compared to polyacrylic acid.<sup>[60,61,62]</sup>

### Sealing ability

Capseali and capseal ii especially capseal ii showed good sealing ability, comparable to that of ah plus when done under anaerobic bacterial leakage. The new cps (capseali, capseal ii) showed sufficient biocompatibilities than other sealers. Sodium phosphate has a ph of 7.4 and promotes hydroxyapatite formation compared to polyacrylic acid. In in vitro fesem analysis, cpc sealants tend to adhere to the dentin surfaces of the canal wall and diffuse more deeply into open dentin tubules than grossman cement.<sup>[64]</sup> The reason for this result is that the particles of the deposited cpc seal have a smaller diameter. These fesem observations indicated that capseal conforms closely and uniformly to the dentin surfaces of the root canal walls and also appears to infiltrate the dentin wall. Many researchers have found that both mineral trioxide aggregates and portland cement have similar physical, chemical and biological properties and even their mechanism of action has no difference. Fesem analysis and leak testing showed that capseal ii, which contained white portland cement, had better sealing properties than capseali, which contained grayportland cement. This result appears to be due to the particle properties of the 2 cements, including the particle size. The smaller the particle size, the easier and faster the cement can be mixed, resulting in a smoother and more fluid cement mix.<sup>[64]</sup>

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