Review Article

# A Review of Endodontic Bioceramics

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**Abstract**

**Background and Aim:** The use of ceramics has a long history. A new category of these materials was used in medicine in 1960 introduced as bioceramics. Biocompatibility, osteoinductivity and sealing ability are among the most favorable characteristics of endodontic bioceramics. Introduction of mineral trioxide aggregate (MTA) revolutionized endodontics and this new era is progressively growing.

**Materials and Methods:** This article reviews endodontic bioceramic materials in the Iranian market such as different types of MTA (ProRoot, Angelus, Root MTA), calcium enriched mixture (CEM) cement, Endo Sequence, iRoot products and MTA Fill apex sealer. Electronic search was carried out for the existing literature in PubMed, Medline and Google Scholar from July 1995 to January 2016 and more clinically applicable data were collected.

**Conclusion:** Favorable characteristics and promising results of bioceramics make them suitable for use in endodontics and new products of this generation are increasingly introduced to the dental market.

**Key Words:** Endodontics, Bioceramics, Root Canal Filling Materials, Root Canal sealant

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## Introduction

Use of ceramics dates back to long ago. The American Ceramic Society defines ceramics as mineral, non-metal substances, which have a crystalline structure. Ceramics are substances between metals and non-metals and include alumina (combination of aluminum and oxygen), calcia (combination of calcium and oxygen) and nitride (combination of silicon and nitrogen) [1]. The crystalline structure of ceramics may vary from a completely regular to totally amorphous (glass) form [2]. In dentistry, ceramics refer to non-metal mineral substances made of oxygen in combination with one or more metal, non-metal or metalloid elements such as aluminum, calcium, lithium, magnesium, potassium, phosphorus, silicon, zirconium and titanium. Thus, a precise definition for ceramics is not available [1,2]. In dentistry, ceramics are used for the fabrication of porcelain and metal crowns, glass ionomers and dental prostheses and they are therefore referred to as dental ceramics [3]. Use of ceramics in dentistry dates back to the 18$^{th}$ century [1] but in the 1960s, the idea of using ceramics with special designs for medical purposes such as restoration and reconstruction of injured tissues was suggested [3]. In 1967, some types of glass and ceramics were introduced that could bond to viable bone and

named "bioglass" [4-6]. Bioceramics are defined as a type of biomaterial with optimal biocompatibility for use for medical and dental purposes. They include alumina, zirconia, bioactive glass, coatings, composites, hydroxyapatite and resorbable calcium phosphate and radiotherapy glasses [4-7]. Bioceramics can be single-crystal (sapphire), multi-crystal (alumina and hydroxyapatite), composite (stainless steel, fiber-reinforced bioglass), polyethylene hydroxyapatite, bioglass or glass-ceramic (CeraVita or A/W glass-ceramic) [3]. Application of bioceramics in orthopedics is extensive and they are used for joint or tissue replacement, coatings that increase the biocompatibility of metal implants and bioceramics that are used as a resorbable scaffold for tissue regeneration [3,5,7]. Thus, definition of bioceramics as a group of materials comprised of calcium silicate and calcium phosphate is a mistake made in some articles [8,9]. Glass and bioglass bioceramics with different commercial brands are used in dentistry.

Porous ceramics such as materials with calcium phosphate base are used for regeneration of bone defects such as calcium silicate materials like MTA and Bio Aggregate that are used as root repair materials [3,5]. Based on tissue reaction, bioceramics are divided into three groups:

Bioinert bioceramics: These bioceramics do not react with biological systems such as alumina and zirconia [5].

Bioactive bioceramics: These bioceramics have a long durability in tissues and only react with tissues at their contact interface [5].

Biodegradable bioceramics: These bioceramics can be dissolved and absorbed by tissues and are eventually replaced with tissue or participate in the composition of tissue (such as tricalcium phosphate) [3-6].

Ceramics are often made of several compounds and single-component ceramics are rare (such as diamond made of carbon only) [1]. Most ceramics are made of several elements. However, they are all made of mineral components. Thus, the term bioceramics for some types that are composed of ceramics and other materials such as resin is a common mistake and "biocomposite", "composites containing bioceramic filler" or "sealers containing bioceramic fillers" are more appropriate terms. However, to avoid complexity, we continue to use the term "bioceramics" in this review. Calcium silicate is only one branch of bioceramics and it appears that introduction of MTA (calcium silicate bioceramic) as the most famous bioceramic in endodontics is responsible for mistakes in classification.

Endodontic bioceramics are non-toxic substances that are not susceptible to moisture or blood. Thus, they are not technique-sensitive. They have acceptable dimensional stability and have insignificant setting expansion. Thus, they have excellent sealing ability. After setting, their solubility decreases. Therefore, they can provide long-term seal and their pH at the time of setting is above 12 because they release hydroxyl ions during their setting reaction. When their setting is not completed, they have antibacterial effects and after setting, they are biocompatible and bioactive. Endodontic bioceramics release calcium hydroxide in contact with tissue fluids, which reacts with phosphate in tissue fluids and produces hydroxyapatite; this can explain their inductive properties in some cases [5,10].

This article reviews endodontic bioceramic materials available in the Iranian market such as different types of MTA (ProRoot, Angelus, Root MTA), CEM cement, EndoSequence, iRoot products and MTA Fill apex sealer. Electronic search was carried out for the existing literature in PubMed, Medline and Google Scholar from July 1995 to January 2016 and more clinically applicable data were collected.

**Endodontic bioceramics:**

*Mineral trioxide aggregate:*

Some researchers believe that MTA in its original form is a classic bioceramic, with some added heavy metals. It has been the topic of many research studies in dentistry and has all the afore-mentioned properties of bioceramics [5]. The primary formulation of MTA was introduced in the 1990s and marketed by the Dentsply International (Dentsply Tulsa Dental, Johnson City, USA). MTA is a mixture of dicalcium silicate, tricalcium silicate, tricalcium aluminate, gypsum, tetracalcium aluminoferrite and 20% bismuth oxide, which is added as radio pacifier to change the physical properties of MTA [11-13]. The primary formulation of MTA was based on 75%

Portland cement and had a gray color; however, it is different from Portland cement since the Portland cement contains heavy metals [14], does not have bismuth oxide [15], contains alumina, has a different method of fabrication and stronger structure (due to absence of bismuth oxide) [13] and contains potassium [16]. Since the gray type causes tooth discoloration, white MTA was introduced to the market in 2002; however, the white type also causes some degrees of discoloration due to the presence of iron oxides in its formulation [17]. The white MTA has less iron aluminum and magnesium than gray MTA and smaller particles [7,12,15,17,18].

When mixed with water, MTA forms calcium silicate hydrate gel and calcium hydroxide [19,20]. Over time, this hydrated gel dries and forms a calcium ciliate matrix with calcium hydroxide penetrated into its porosities [21]. Torabinejad et al, in 1995 stated that the pH of MTA after mixing is 10.2, which reaches 12.5 after three hours [10]. Chang et al, in 2005 showed that the pH of white MTA was significantly higher than that of gray MTA for a long period of time after mixing [22].

Setting expansion is a positive property of MTA and it has been shown that gray MTA has higher setting expansion than white MTA [23]. The setting time of MTA is different depending on the measurement method. Primary setting occurs within 45 minutes [22] but final setting requires 140 minutes [22] to 250 minutes [24]. It has been suggested to mix three portions of powder with one portion of liquid. If MTA powder packed in the canal is given adequate time, it eventually sets by absorbing moisture from the accessory canals and cementum [25]. However, the performance of MTA in dry environment is not as good as that in moist environment [26]. On the other hand, high amounts of water cause greater porosity and dissolution (wash out) of MTA at the time of setting and lower strength of set MTA [27]. Although most studies indicate no or minimal dissolution of MTA (10,28], a 78-day study by Fridland and Rosado in 2005 showed increased solubility of MTA. An interesting finding was that increasing the percentage of liquid to powder from 28% to 33% increased its solubility [29].

One drawback of MTA is its difficult handling, which is due to its low cohesive strength [30]. The white MTA has more homogenous particles than the gray MTA [31] and has fewer large particles, which enhances its handling [18]. Several materials have been used to improve handling and decrease the setting time of MTA such as calcium chloride, K-Y jelly (Johnson & Johnson, New Brunswick, NJ, USA), chlorhexidine [32], disodium hydrogen phosphate [33] and calcium formate [34]. Addition of 1% methylcellulose and 2% calcium chloride to MTA confers a consistency similar to that of zinc oxide eugenol to MTA and decreases its setting time by one hour [35]. A previous study for single-visit application of MTA suggested mixing MTA with 5% calcium chloride or sodium hypochlorite gel instead of water [32]. Use of sodium hypochlorite gel improved MTA handling as well. On the other hand, it has been shown that mixing MTA with sodium hypochlorite or lidocaine negatively affects the formation of calcium hydroxide [36]. On the other hand, freshly mixed MTA with 3% sodium hypochlorite decreased the viability of fibroblasts but this effect was eliminated after 24 hours. Mixing MTA with water, saline, calcium chloride and lidocaine had no effect on biocompatibility of MTA [37]. Acidic environment during MTA setting decreases the formation of calcium hydroxide (changes hydration behavior) [38], decreases push out strength [39], compromises surface hardness and increases porosity (with further reduction of pH) [40]. Thus, in composite restorations, it is recommended to perform acid etching at least 96 hours after mixing MTA [41]. Another shortcoming of MTA is causing grayish discoloration in teeth, which is greater by the use of gray MTA but is also caused by the application of white MTA [42-46]. Iron and manganese salts are responsible for this discoloration [43]. Grayish discoloration caused by the white MTA is aggravated in presence of blood [44]. Thus, in regenerative treatments of anterior teeth, use of dentin bonding agents should be considered to prevent discoloration [47]. Contact of MTA or other materials containing bismuth with sodium hypochlorite (as in open apex teeth) causes dark brown discoloration [48]. In case of occurrence of discoloration, internal bleaching may be effective [42]. A previous study assessed the effect of bleaching agents on MTA and showed that these

materials cause surface modifications in MTA and it cannot serve as a suitable barrier against bleaching agents [49]. Another barrier is suggested for use over MTA. Primary cellular inflammatory response to MTA is less than ideal. The biocompatibility of white MTA in the first three days following application is higher than that of gray MTA. This became reverse in the first week and the two were not significantly different in this regard from the third week on [50]. Subcutaneous implantation of MTA causes severe inflammatory reaction along with coagulation necrosis and calcification in connective tissue [51]. Addition of disodium hydrogen phosphate to white MTA increased its biocompatibility [52].

**MTA Angelus (Angelus soluçõesodontológicas, Londrina, PR, Brazil):**

MTA Angelus is available in two forms of white (for esthetic regions) and gray containing 80% Portland cement and 20% bismuth oxide. The amount of bismuth oxide in gray MTA Angelus is less than that in gray ProRoot MTA. The amount of aluminum oxide present in MTA Angelus is 237% higher than that in white ProRoot MTA. The amount of magnesium oxide present in gray ProRoot MTA is 486% higher than that in MTA Angelus [17]. Homogeneity of MTA Angelus is less than that of ProRoot MTA [16]. Also, it is available in self-cure and light-cure forms. A clinical study showed that light cure MTA Angelus had a similar performance to MTA in a 60-day period but did not cause mineralization [53]. Calcium sulfate is not incorporated in the composition of MTA Angelus in order to decrease setting time (about 10 minutes). The amount of bismuth oxide in MTA Angelus is less than that in ProRoot MTA but its calcium content is higher (about 45%) [54]. The pH and release of calcium ionsare higher in MTA Angelus than ProRoot MTA, which are probably due to the higher amount of cement and higher calcium content [54,55]. The gray MTA Angelus has greater release of calcium ions and higher pH than the white type [56]. Both white and gray MTA Angelus have less opacity than ProRoot MTA [57].

**Root MTA:**

This type of MTA was produced by Lotfi in Tabriz University of Medical Sciences and marketed by Salamyfar Company. It is a cheaper type of MTA [58]. It contains 41.64% calcium oxide, 18.58% SiO2, 15.18% bismuth oxide, 3.41% aluminum oxide, 2.08% magnesium oxide and small amounts of iron oxide, sulfur oxide, phosphorus oxide, titanium oxide, sodium oxide, chlorine, water and carbon dioxide. Size of particles ranges between 5-60μ and is smaller than that of gray ProRoot MTA [17]. Assessment of biocompatibility of ProRoot MTA and Root MTA showed no cell viability at 48 and 168 hours for ProRoot and 72 hours for Root MTA but the difference was not significant [59]. Comparison of apical leakage of white MTA, Root MTA and CEM cement showed no difference in microleakage of these materials [60,61], although addition of 3% and 5% calcium chloride decreased the compressive strength of MTA. Addition of calcium chloride to Root MTA increased compressive strength in the first hour, but after three hours, it was the same as that in Root MTA without calcium chloride. Calcium chloride not only increased the compressive strength, but also accelerated the reaction. The same results were obtained for di-sodium hydrogen phosphate. Addition of these materials could not prevent the negative effect of blood contamination on reduction of compressive strength [62]. Root MTA has been used for restoration of strip perforation [58] and furcal perforation [63]. Despite higher inflammatory response of Root MTA compared to ProRoot MTA, these two materials can be used alternately for furcal perforation repair [63]. The antimicrobial effects of Root MTA and ProRoot MTA on Actinobacillus actinomycetemcomitans were not significantly different [64]. Assessment of cytotoxicity of ProRoot MTA, Root MTA and Portland cement on human gingival fibroblasts showed that these materials had similar biocompatibility in vitro [65]. It has been stated that Root MTA can be used as an alternative to MTA [2,58,63,65].

**Biodentine:**

Biodentine (Septodont, Saint-Maur-des-Fosse´s Cedex, France) is a new bioceramic cement, which is supplied in the form of powder and liquid. The powder contains calcium silicate and zirconium oxides and the liquid contains sodium, magnesium, chlorine and water [66]. Zirconium oxide serves as a radiopacifier and calcium chloride serves as setting reaction accelerator [5]. The manufacturer

claims that calcium carbonate present in the powder serves as a filler and the liquid contains a water soluble polymer aiming to decrease water content. The primary mixing of the capsulesis done by a mixer similar to amalgamator and the required consistency is obtained manually. Setting time of this material is short (about 10-12 minutes) and is shorter than that of MTA [67]. Discoloration due to exposure of Biodentine or BioAggregate (both are devoid of bismuth oxide) to chlorhexidine and sodium hypochlorite is less than that of white MTA and thus, they can be an alternative to MTA in esthetic regions [68].

The release of calcium ions from Biodentine is higher than that from MTA, EndoSequence BC, BioAggregate and Intermediate Restorative Material [45,69]. Grech et al, in 2013 showed that the pH of Biodentine was 11.7 in the first day and reached 12.2 from the second day on and remained constant during 28 days [69]. In 2011, Han and Okiji compared the bond failure of Biodentine and MTA and showed that the mode of failure in MTA was mainly adhesive while it was cohesive in Biodentine. The authors believed that this finding was due to smaller size of particles in Biodentine, which enabled their deeper penetration into dentinal tubules and increase in tag formation and creation of micromechanical anchorage [70]. Higher push out bond strength in Biodentine is due to smaller size and homogeneity of Biodentine particles [71]. It has been shown that MTA has lower strength when exposed to chlorhexidine while Biodentine showed no change in presence of chlorhexidine, sodium hypochlorite and saline [72]. Despite these advantages and dentin remineralization due to long-term contact with Biodentine, reduction in integrity of dentin collagen matrix has been noted. Due to the effect of Biodentine on collagen, it should be used with caution on thin dentinal walls [73]. Considering less discoloration caused by Biodentine compared to MTA (especially in contact with irrigants such as sodium hypochlorite or chlorhexidine), Biodentine(due to absence of bismuth in its composition) can be a suitable alternative to MTA in esthetic regions [68,74]. Similar to MTA, presence of blood increases the discoloration caused by Biodentine and no significant difference was noted in discoloration caused by MTA and Biodentine in presence of blood [75]. Its use for vital pulp therapy [76], perforation repair [72], or root apical plug [77] is increasing and the manufacturer claims that it can serve as dentin substitute. Less radiopacity of Biodentine than MTA causes difficulties in diagnosis in its use as a plug [78,79].

**CEM cement:**

It is produced by BioniqueDent company in Iran and is composed of calcium oxide (51.81%), silica oxide (6.28%), aluminum oxide (0.95%), magnesium oxide (0.23%), sulfur oxide (9.48%), phosphorus oxide (8.52%), sodium oxide (0.35%), chlorine (0.18%), water, carbon dioxide and some other materials (22.2%) [80]. Except for some rare elements, the concentration of other constituents of CEM is different from that in white and gray Portland cement [17]. Comparison of CEM and ProRoot MTA shows that they have almost similar pH, working time and dimensional changes but CEM cement has shorter setting time (less than one hour), less film thickness and higher flow [80]. CEM cement has no significant difference with white ProRoot MTA in alkaline pH and release of calcium ions. But one hour after mixing of CEM cement, it releases higher amounts of phosphate compared to Portland cement and white ProRoot MTA [81]. Radiopacity of this material is about half of the radiopacity of MTA [82], which is less than the required amount for endodontic sealers (equal to 3mm of aluminum). It has been shown that one week after exposure of CEM cement to phosphate buffered saline, crystals similar to standard hydroxyapatite crystals are formed on its surface, which indicate its bioactivity [83]. Antimicrobial activity of CEM cement and calcium hydroxide is significantly higher than that of white and gray ProRoot MTA and Portland cement [84] but CEM cement and white ProRoot MTA are not significantly different in terms of antifungal effect on Candida albicans [85].

The sealing ability of CEM cement in many studies was similar to that of MTA (60,86,87]. Blood contamination has no significant effect on sealing ability of MTA and CEM cement but CEM cement had superior sealing ability after saliva contamination [88]. Several case reports are present on the use of CEM cement for pulpotomy of immature [89] and mature [90] teeth, pulp

capping [91], furcal perforation repair [92], repair of external root resorption defects [93], retrograde filling [94], and regenerative endodontic treatments [95]. A clinical trial of mature molars with irreversible pulpitis treated with CEM cement and MTA showed that the teeth in the two groups were not significantly different in terms of radiographic and clinical signs and symptoms at one year and both had a success rate of over 90% [96]. The same results were obtained in a multi-center study on teeth with the same conditions and it was stated that pulpotomy of teeth with irreversible pulpitis with CEM cement is superior to conventional endodontic treatment [97].

**EndoSequence:**

EndoSequence root repair material (ERRM) is produced by Brasseler company and is supplied in the form of a moldable putty (marketed as iRoot BP Plus) and a syringe containing paste with the ability to be injected into the canal. EndoSequence BC obturation system is another product of this company (comprised of gutta-percha and EndoSequence BC sealer). All forms of ERRM are composed of calcium silicate, zirconium oxide, tantalum oxide, monobasic calcium phosphate, fillers and plasticizers [7,98]. They are comprised of nanospheres that can penetrate into dentinal tubules and set using their moisture [98]. The ERRM putty is similar to gray MTA in terms of crystallographic structure of surface [98]. Deposition of apatite and increase in calcium and phosphorus content in the surface were noted after two months of immersion in phosphate buffered saline [99]. The compressive strength of ERRM is similar to that of MTA but due to forming tag-like structures in dentin, it causes micromechanical interlocking and bond to dentin, which are not seen in use of MTA [7]. According to the manufacturer, working time of ERRM is 30 minutes and its setting time is 4 hours. It sets in presence of moisture and its pH is 12.4, which is maintained during its setting. However, its superficial pH in simulated root resorption defects was less than that of ProRoot MTA [100]. In terms of antibacterial effect on Enterococcus faecalis, no difference was noted between putty and syringe form of ERRM and white ProRoot MTA [101]. A recent study showed that microhardness of ERRM decreases in acidic environment, its porosity increases and its microscopic crystalline structure decreases [102].

Cytotoxicity of ERRM is the same as that of ProRoot MTA and MTA Angelus [98]. Another study on osteoblast-like cells showed that ERRM putty in contrast to white ProRoot MTA decreased cellular and alkaline phosphatase activity [103]. Viability and proliferation of dental pulp stem cells in presence of ERRM and MTA are preserved. Also, in presence of ERRM and MTA, secretion of angiogenic factors from these cells increases and thus, ERRM is suggested as a suitable alternative for direct pulp capping [104]. Chen et al. assessed cone beam computed tomography and micro computed tomography scans to monitor the process of healing after use of ERRM and MTA and reported that ERRM showed superior results [105]. However, periapical radiography showed no significant difference between the two. Histological assessment showed greater root coverage by cementum-like, bone-like and PDL-like tissues in presence of ERRM [105]. Comparison of subcutaneous implantation of these two materials revealed interesting results as well. Inflammatory reaction of MTA after seven and 30 days was higher and more areas of accumulation of mononuclear cells, abscess formation and necrosis were seen in the MTA group. The thickness of fibrotic capsule in the MTA group was also significantly greater [106]. It has been shown that the discoloration caused by ERRM is less than that of MTA [74,107] but discoloration of ERRM similar to that of MTA and Biodentine increases in presence of blood and is aggravated over time and no significant difference was noted among them in terms of discoloration [75].

The iRoot products include iRoot SP, iRoot BP and iRoot BP Plus. These products are produced by the Innovative Bioceramix Inc. (Vancouver, Canada). According to the manufacturer, iRoot SP is the same as EndoSequence BC sealer. The iRoot BP and iRoot BP Plus are insoluble, ready to use, devoid of aluminum and opaque, and are different from each other in terms of consistency. The iRoot BP is an injectable white paste but iRoot BP Plus has a putty-like consistency [2]. A study showed that ERRM putty is also marketed with the brand name “iRoot BP Plus” [7]. However, despite the

similar structure of these two materials [12], no such information was found in the brochures of the materials.

According to the manufacturer, iRoot Plus has a setting time of 2 hours but it has been shown that its complete setting takes 7 days [108]. No difference was noted in the ability of iRoot BP Plus and MTA for the formation of dentinal bridge in teeth that have undergone pulp capping [109]. Comparison of biocompatibility of these two materials showed that cell viability was less in exposure to iRoot BP Plus compared to ProRoot MTA [110]. The iRootSF (Brasseler, Savannah, GA, USA) is another member of this family and is among the permanent restorative materials. It has a base of calcium silicate but does not contain aluminum. Its handling properties are better and its setting time has decreased (one hour) [108].

BioAggregate is a product of Innovative BioCeramix Inc., (Vancouver, Canada) and has been produced using nano-technology, However, in contrast to other products of this company, it is not premixed and is supplied in the form of powder and liquid. Its working time is 5 minutes, which increases if covered with gauze [2].

**BC Sealer and iRoot SP:**

As mentioned earlier, according to the manufacturer, EndoSequence BC Sealer and iRoot SP root canal sealer are the same product [2]. This sealer is premixed and contains zirconium oxide (radiopacifier), tricalcium silicate, dicalcium silicate, colloidal silica, calcium silicate, monobasic calcium phosphate, calcium hydroxide, fillers and plasticizers. This is a hydrophilic sealer and the moisture inside the tubules causes its setting. Its working time is more than 4 hours at room temperature and its setting time depends on the amount of moisture and varies from 4 hours to 10 hours in very dry canals [111]. It has been shown that the apical sealing ability of iRoot SP with a single gutta-percha cone is the same as that of obturation with AH26 sealer and continuous wave filling [112]. In another study, dentin bond strength of obturation with gutta-percha along with this sealer was higher than that of MTA Fillapex and AH Plus [113] but Shokohinejad et al. did not find a significant difference in bond strength of BC Sealer and AH Plus with gutta-percha [114]. The push-out bond strength of roots bulk-filled with iRoot SP was less than that of canals filled with gutta-percha [115]. Application of calcium hydroxide before filling the root canals with iRoot SP increases the bond of this sealer to dentin and is as efficient as AH Plus [116]. It has been shown that presence of phosphate buffered saline inside the root canals increases the bond strength of EndoSequence BC sealer with gutta-percha at one week. But after two months, presence or absence of phosphate buffered saline had no effect in this respect [117]. The alkaline pH created by this sealer remains for seven days and the antimicrobial effects of this sealer on Enterococcus faecalis remain for seven days after mixing [118]. Water is necessary for final setting of this material. Water absorbed from the environment and water formed as the result of reaction of calcium phosphate and calcium hydroxide deposits is used for the formation of calcium silicate hydrate phase and causes deposition of hydroxyapatite and increases sealer-dentin bond [119]. It has been shown that during retreatment, SP BC sealer cannot be completely removed from the root canal by conventional methods such as chloroform, heat and filing [111]. The solubility of Fill apex and iRoot SP sealers is higher than that of AH Plus and MTA Angelus and is not in agreement with the standards but the solubility of iRoot SP is higher than that of Fillapex [120]. Another study found no significant difference in solubility of iRoot SP and AH Plus, and it was in agreement with the standards. Also, iRoot SP absorbed more water but no difference was noted in the apical seal provided by these two materials [121]. Radiopacity of this sealer equals 3.84 mm of aluminum, which is about half the opacity of AH plus but it is in agreement with the standards (minimum of 3 mm of aluminum) [9]. BC Sealer has moderate cytotoxic effects on osteoblasts at five weeks [119] but another study showed that iRoot SP and MTA induced differentiation of dental papilla stem cells to odontoblast-like cells and induced biomineralziation [122]. No difference in inflammatory response to intraosseous and subcutaneous placement of iRoot SP and MTA was noted in rats and both of these materials showed biocompatibility [123].

**MTA Fillapex:**

This sealer is produced by the Angelus Company

(Brazil) and has the physical and chemical properties of resin sealers and biological properties of MTA [124]. The composition of this material after mixing includes MTA, salicylate resin, natural resin, bismuth and silica [125]. High amounts of calcium and carbon are present on the surface of this material [120]. However, after seven days, the amount of carbon decreases, which is probably due to the degradation of this polymer. As the result, high water sorption occurs and calcium ions are released [7]. This material has high solubility and high release of calcium ions [120,126]. Its solubility is higher than standard and due to release of calcium during its dissolution, it shows higher antimicrobial activity than some other sealers [126]. In contrast to the alkaline pH of this sealer before and after setting, its antimicrobial activity against Enterococcus faecalis was no longer present after setting [127]. The bond strength of this material is significantly lower than that of AH Plus and iRoot SP and the reason is less adhesion of tag-like structures [128]. Comparison of bond of iRoot SP and MTA Fill apex sealers in dry, moist and wet conditions showed that maximum bond of these sealers is achieved in moist conditions and minimum bond strength is achieved in wet conditions. In wet conditions, Fillapex did not bond to canal wall. The bond of iRoot SP in all conditions was higher than that of Fillapex [113]. Use of calcium hydroxide inside the canal for seven days prior to root canal filling by Fillapex sealer decreased its bond [116]. Another study showed that smear layer removal had no adverse effect on sealing ability of iRoot SP and Fillapex but the sealing ability of Fillapex was less than that of iRoot SP [129]. No difference was noted in fracture strength of teeth filled with gutta-percha and Fillapex, iRoot SP and AH Plus sealers [130]. Radiopacity (equal to 7.06 mm of aluminum) and flow of this material were higher than those of AH Plus sealer [124]. However, another study showed that AH Plus is more radiopaque [131]. Also, use of ultrasonic tool causes greater penetration depth of sealer into dentinal tubules compared to the use of Lentulo or reverse rotation of rotary instruments [132]. Despite this high flow rate, in retreatment, none of the AH Plus or Fillapex sealers could penetrate into dentinal tubules [133].

Comparison of connective tissue response to Fillapex, iRoot SP and MTA Angelus showed that Fillapex was still cytotoxic for subcutaneous tissues even 90 days after its application [134]. Fillapex was more cytotoxic two weeks after setting compared to freshly mixed sealer or sealer set for one week. Reduction of cell viability after exposure to MTA Fillapex was significant, which may be due to the release of lead from the set sealer [135] or its resin content [125]. Only one study assessed the reaction of bone to this sealer and revealed that this sealer was biocompatible but presence of MTA in its formulation did not cause regeneration of bone defect. Inflammatory reaction and delayed formation of dentinal bridge in this study was attributed to the presence of silicate resins in sealer composition [136]. But it can induce the formation of nucleation sites and apatite [61].

**Conclusion**

Endodontic bioceramics are non-toxic, non-moisture sensitive materials with optimal dimensional stability, excellent sealing ability, alkaline pH and osteoinductivity. Due to drawbacks such as causing tooth discoloration, difficult handling and long setting time, studies are still ongoing on these materials. A number of bioceramics have been introduced to the market such as EndoCem MTA, EndoCemZr, RetroMTA, Ortho MTA, mechanically mixed MTA, MTA Plus, gray MTA Plus, CimentoEndodôntico, CER, Rapido or fast endodontic cement, MTA caps, nano white MTA, Theracal, Generex A, B, bioactive glass and bioceramic gutta-percha. Thus, clinicians must enhance their knowledge about these bioceramics since they have shown promising results and may cause revolutionary changes in endodontic treatment in near future.

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