

## A Review of Endodontic Bioceramics

H. Assadian <sup>1</sup>, E. Hamzelouei Moghaddam <sup>2</sup>✉, A. Amini <sup>3</sup>, K. Nazari Moghaddam <sup>4</sup>, M. Hashemzahi <sup>5</sup>.

<sup>1</sup> Assistant Professor, Department of Endodontics, School of Dentistry, Shahed University, Tehran, Iran

<sup>2</sup> Assistant Professor, Department of Endodontics, School of Dentistry, Lorestan University of Medical Sciences, Khorramabad, Iran

<sup>3</sup> Postgraduate Student, Department of Endodontics, School of Dentistry, Islamic Azad University, Tehran, Iran

<sup>4</sup> Associate Professor, Department of Endodontics, School of Dentistry, Shahed University, Tehran, Iran

<sup>5</sup> Postgraduate Student, Department of Endodontics, School of Dentistry, Shahed University, Tehran, Iran

### 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

✉ Corresponding author:  
E. Hamzelouei Moghaddam,  
Assistant Professor,  
Department of Endodontics,  
School of Dentistry, Lorestan  
University of Medical Sciences,  
Khorramabad, Iran

hamzelouei@yahoo.com

Received: 27 Aug 2015

Accepted: 21 Mar 2016

➤ **Cite this article as:** Assadian H, Hamzelouei Moghaddam E, Amini A, Nazari Moghaddam K, Hashemzahi M. A Review of Endodontic Bioceramics. J Islam Dent Assoc Iran. 2016; 28(1):20-33. DOI: 10.30699/10.30699/jidai.28.1.20

### 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<sup>th</sup> 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 ions are 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% SiO<sub>2</sub>, 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-Fossés 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 capsules is 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 Bioceramics 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 biomineralization [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.

### References

1. Sukumaran V, Bharadwaj N. Ceramics in dental applications. *Trends Biomater.* 2006;20(1):7-11.
2. Ceramic. Available at: <https://en.wikipedia.org/wiki/Ceramic>/Accessed August 27, 2015.
3. Hench LL. The story of Bioglass®. *J Mater Sci Mater Med.* 2006 Nov; 17(11):967-78.
4. Malhotra S, Hegde MN, Shetty C. Bioceramic technology in endodontics. *Br J Med and Med Res.*



- 2014 Apr; 4(12):2446-2454.
5. Trope M, Bunes A, Debelian G. Root filling materials and techniques: Bioceramics a new hope? *Endod Topics*. 2015 May;32(1):86-96.
  6. Best S, Porter A, Thian E, Huang J. Bioceramics: Past, present and for the future. *J of the Europ Ceramic Soc*. 2008 Dec;28(7):1319-27.
  7. Wang Z. Bioceramic materials in endodontics. *Endod Topics*. 2015 May;32(1):3-30.
  8. Koch K, Brave D. Bioceramic technology-the gamechanger in endodontics. *Endod Practice US*. 2009; Apr:13-7.
  9. Candeiro GT, Correia FC, Duarte MA, Ribeiro-Siqueira DC, Gavini G. Evaluation of radiopacity, pH, release of calcium ions, and flow of a bioceramic root canal sealer. *J of Endod*. 2012 Jun; 38(6):842-5.
  10. Torabinejad M, Hong CU, McDonald F, Pitt Ford TR. Physical and chemical properties of a new root-end filling material. *J Endod*. 1995 Jul; 21(7):349-53.
  11. Primus CM, Gutmann JL, Yapp R, Tay F. Physical Properties of New Generation Tricalcium Silicate Dental Materials. *Bioceram Dev Appl*. 2014 Oct;4(1):1-9.
  12. Shen Y, Peng B, Yang Y, Ma J, Haapasalo M. What do different tests tell about the mechanical and biological properties of bioceramic materials? *Endod Topics*. 2015 May; 32(1):47-85.
  13. Camilleri J. Hydration mechanisms of mineral trioxide aggregate. *Int Endod J*. 2007 Jun; 40(6):462-70.
  14. Dammaschke T, Gerth HU, Züchner H, Schäfer E. Chemical and physical surface and bulk material characterization of white ProRoot MTA and two Portland cements. *Dent Mater*. 2005 Aug; 21(8):731-8.
  15. Asgary S, Parirokh M, Eghbal MJ, Stowe S, Brink F. A qualitative X-ray analysis of white and grey mineral trioxide aggregate using compositional imaging. *J Mater Sci Mater Med*. 2006 Feb;17(2):187-91.
  16. Song JS, Mante FK, Romanow WJ, Kim S. Chemical analysis of powder and set forms of Portland cement, gray ProRoot MTA, white ProRoot MTA, and gray MTA-Angelus. *Oral Surg Oral Med Oral Pathol Oral Radiol and Endod*. 2006 Dec;102(6):809-15.
  17. Asgary S, Eghbal MJ, Parirokh M, Ghoddsi J, Kheirieh S, Brink F. Comparison of mineral trioxide aggregate's composition with Portland cements and a new endodontic cement. *J Endod*. 2009 Feb; 35(2):243-50.
  18. Camilleri J, Montesin FE, Brady K, Sweeney R, Curtis RV, Ford TRP. The constitution of mineral trioxide aggregate. *Dent Mater*. 2005 Apr; 21(4): 297-303.
  19. Holland R, De Souza V, Nery MJ, Otoboni Filho JA, Bernabé PF, Dezan E. Reaction of rat connective tissue to implanted dentin tubes filled with mineral trioxide aggregate or calcium hydroxide. *J of Endod*. 1999 Mar;25(3):161-6.
  20. Holland R, Souza Vd, Nery MJ, Faraco Júnior IM, Bernabé PFE, Otoboni Filho JA, et al. Reaction of rat connective tissue to implanted dentin tubes filled with a white mineral trioxide aggregate. *Braz Dent J*. 2002;13(1):23-6.
  21. Gandolfi MG, Taddei P, Tinti A, Prati C. Apatite-forming ability (bioactivity) of ProRoot MTA. *Int Endod J*. 2010 Oct;43(10):917-29.
  22. Chng HK, Islam I, Yap AU, Tong YW, Koh ET. Properties of a new root-end filling material. *J Endod*. 2005 Sep;31(9):665-8.
  23. Storm B, Eichmiller FC, Tordik PA, Goodell GG. Setting expansion of gray and white mineral trioxide aggregate and Portland cement. *J Endod*. 2008 Jan; 34(1):80-2.
  24. Ding SJ, Kao CT, Shie MY, Hung C, Huang TH. The physical and cytological properties of white MTA mixed with Na<sub>2</sub>HPO<sub>4</sub> as an accelerant. *J Endod*. 2008 Jun;34(6):748-51.
  25. Budig CG, Eleazer PD. In vitro comparison of the setting of dry ProRoot MTA by moisture absorbed through the root. *J Endod*. 2008 Jun; 34(6):712-4.
  26. Gancedo-Caravia L, Garcia-Barbero E. Influence of humidity and setting time on the push-out strength of mineral trioxide aggregate obturations. *J Endod*. 2006 Sep;32(9):894-6.
  27. Walker MP, Diliberto A, Lee C. Effect of setting conditions on mineral trioxide aggregate flexural strength. *J Endod*. 2006 Apr; 32(4): 334-6.
  28. Shie MY, Huang TH, Kao CT, Huang CH, Ding SJ. The effect of a physiologic solution pH on properties of white mineral trioxide aggregate. *J Endod*. 2009 Jan;35(1):98-101.
  29. Fridland M, Rosado R. MTA solubility: a long term study. *J Endod*. 2005 May; 31(5):376-9.
  30. Hsieh SC, Teng NC, Lin YC, Lee PY, Ji DY, Chen CC, et al. A novel accelerator for improving the handling properties of dental filling materials. *J Endod*. 2009 Sep; 35(9):1292-5.

31. Komabayashi T, Spångberg LS. Comparative analysis of the particle size and shape of commercially available mineral trioxide aggregates and Portland cement: a study with a flow particle image analyzer. *J Endod.* 2008 Jan; 34(1):94-8.
32. Kogan P, He J, Glickman GN, Watanabe I. The effects of various additives on setting properties of MTA. *J Endod.* 2006 Jun; 32(6):569-72.
33. Huang TH, Shie MY, Kao CT, Ding SJ. The effect of setting accelerator on properties of mineral trioxide aggregate. *J Endod.* 2008 May; 34(5):590-3.
34. Wiltbank KB, Schwartz SA, Schindler WG. Effect of selected accelerants on the physical properties of mineral trioxide aggregate and Portland cement. *J Endod.* 2007 Oct; 33(10):1235-8.
35. Ber BS, Hatton JF, Stewart GP. Chemical modification of ProRoot MTA to improve handling characteristics and decrease setting time. *J Endod.* 2007 Oct;33(10):1231-4.
36. Zapf AM, Chedella SC, Berzins DW. Effect of additives on mineral trioxide aggregate setting reaction product formation. *J Endod.* 2015 Jan; 41(1):88-91.
37. Jafarnia B, Jiang J, He J, Wang Y-H, Safavi KE, Zhu Q. Evaluation of cytotoxicity of MTA employing various additives. *Oral Surg Oral Med Oral Pathol Oral Radiol and Endod.* 2009 May; 107(5):739-44.
38. Lee YL, Lee BS, Lin FH, Lin AY, Lan WH, Lin CP. Effects of physiological environments on the hydration behavior of mineral trioxide aggregate. *Biomaterials.* 2004 Feb; 25(5):787-93.
39. Shokouhinejad N, Nekoofar MH, Irvani A, Kharrazifard MJ, Dummer PM. Effect of acidic environment on the push-out bond strength of mineral trioxide aggregate. *J Endod.* 2010 May; 36(5):871-4.
40. Namazikhah MS, Nekoofar MH, Sheykhrezae MS, Salariyeh S, Hayes SJ, Bryant ST, et al. The effect of pH on surface hardness and microstructure of mineral trioxide aggregate. *Int Endod J.* 2008 Feb; 41(2):108-16.
41. Kayahan MB, Nekoofar MH, Kazandağ M, Canpolat C, Malkondu O, Kaptan F, et al. Effect of acid-etching procedure on selected physical properties of mineral trioxide aggregate. *Int Endod J.* 2009 Nov; 42(11):1004-14.
42. Belobrov I, Parashos P. Treatment of tooth discoloration after the use of white mineral trioxide aggregate. *J Endod.* 2011 Jul; 37(7):1017-20.
43. Bortoluzzi EA, Araújo GS, Tanomaru JMG, Tanomaru-Filho M. Marginal gingiva discoloration by gray MTA: a case report. *J Endod.* 2007 Mar; 33(3):325-7.
44. Felman D, Parashos P. Coronal tooth discoloration and white mineral trioxide aggregate. *J Endod.* 2013 Apr;39(4):484-7.
45. Han L, Okiji T. Bioactivity evaluation of three calcium silicate-based endodontic materials. *Int Endod J.* 2013 Sep;46(9):808-14.
46. Ioannidis K, Mistakidis I, Beltes P, Karagiannis V. Spectrophotometric analysis of coronal discoloration induced by grey and white MTA. *Int Endod J.* 2013 Feb;46(2):137-44.
47. Akbari M, Rouhani A, Samiee S, Jafarzadeh H. Effect of dentin bonding agent on the prevention of tooth discoloration produced by mineral trioxide aggregate. *Int J Dent.* 2012;2012:563203.
48. Camilleri J. Color stability of white mineral trioxide aggregate in contact with hypochlorite solution. *J Endod.* 2014 Mar;40(3):436-40.
49. Tsujimoto M, Ookubo A, Wada Y, Matsunaga T, Tsujimoto Y, Hayashi Y. Surface changes of mineral trioxide aggregate after the application of bleaching agents: electron microscopy and an energy-dispersive X-ray microanalysis. *J Endod.* 2011 Feb;37(2):231-4.
50. Shahi S, Rahimi S, Lotfi M, Yavari H, Gaderian A. A comparative study of the biocompatibility of three root-end filling materials in rat connective tissue. *J Endod.* 2006 Aug; 32(8):776-80.
51. Yaltirik M, Ozbas H, Bilgic B, Issever H. Reactions of connective tissue to mineral trioxide aggregate and amalgam. *J Endod.* 2004 Feb; 30(2):95-9.
52. Lotfi M, Vosoughhosseini S, Saghir MA, Mesgariabbasi M, Ranjkesh B. Effect of white mineral trioxide aggregate mixed with disodium hydrogen phosphate on inflammatory cells. *J Endod.* 2009 May;35(5):703-5.
53. Gomes-Filho JE, de Faria MD, Bernabé PF, Nery MJ, Otoboni-Filho JA, Dezan-Júnior E, et al. Mineral trioxide aggregate but not light-cure mineral trioxide aggregate stimulated mineralization. *J Endod.* 2008 Jan;34(1):62-5.
54. Oliveira MG, Xavier CB, Demarco FF, Pinheiro AL, Costa AT, Pozza DH. Comparative

- chemical study of MTA and Portland cements. *Braz Dent J.* 2007;18(1):3-7.
55. Duarte MA, Demarchi AC, Yamashita JC, Kuga MC, Fraga Sde C. pH and calcium ion release of 2 root-end filling materials. *Oral Surg Oral Med Oral Pathol Oral Radiol and Endod.* 2003 Mar; 95(3):345-7.
56. de Vasconcelos BC, Bernardes RA, Cruz SM, Duarte MA, Padilha Pde M, Bernardineli N, et al. Evaluation of pH and calcium ion release of new root-end filling materials. *Oral Surg Oral Med Oral Pathol Oral Radiol and Endod.* 2009 Jul; 108(1): 135-9.
57. Parirokh M, Torabinejad M. Mineral trioxide aggregate: a comprehensive literature review-part I: chemical, physical, and antibacterial properties. *J Endod.* 2010 Jan;36(1):16-27.
58. Froughreyhani M, Milani A, Barakatein B, Shiezadeh V. Treatment of strip perforation using Root MTA: A case report. *Iran Endod J.* 2013 Spring; 8(2):80-83.
59. Moazami F, Shahsiah S. The cellular behavior and SEM evaluation of ProRoot and Root MTAs on fibroblast L929. *Iran Endod J.* 2006 Fall; 1(3): 87-92.
60. Kazem M, Eghbal MJ, Asgary S. Comparison of bacterial and dye microleakage of different root-end filling materials. *Iran Endod J.* 2010 Winter; 5 (1):17-22.
61. Salles LP, Gomes-Cornélio AL, Guimaraes FC, Herrera BS, Bao SN, Rossa-Junior C, et al. Mineral trioxide aggregate-based endodontic sealer stimulates hydroxyapatite nucleation in human osteoblast-like cell culture. *J Endod.* 2012 Jul;38(7):971-6.
62. Oloomi K, Saberi E, Mokhtari H, Mokhtari Zonouzi HR, Nosrat A, Nekoofar MH, et al. Evaluation of the effect of blood contamination on the compressive strength of MTA modified with hydration accelerators. *Restor Dent Endod.* 2013 Aug; 38(3):128-33.
63. Jahromi Z, Razavi S.M, Esfahanian V, Feizi GH. Histological evaluation of inflammation after sealing furcating perforation in dog's teeth by four materials. *Dent Res J.* 2006 Autumn-Winter; 3(2): 1-10.
64. Sheykhrezai MS, Aligholi M, Ghorbanzadeh R, Bahador A. A comparative study of antimicrobial activity of ProRoot MTA, Root MTA, and Portland cement on *Actinobacillus actinomycetemcomitans*. *Iran Endod J.* 2008 Fall; 3(4):129-133.
65. Sharifian MR, Ghobadi M, Shokouhinejad N, Assadian H. Cytotoxicity evaluation of ProRoot MTA, Root MTA and Portland cement on human gingival fibroblasts. *Iran Endod J.* 2007 Fall; 2(3): 91-94.
66. Camilleri J, Kralj P, Veber M, Sinagra E. Characterization and analyses of acid-extractable and leached trace elements in dental cements. *Int Endod J.* 2012 Aug;45(8):737-43.
67. Setbon HM, Devaux J, Iserentant A, Leloup G, Leprince JG. Influence of composition on setting kinetics of new injectable and/or fast setting tricalcium silicate cements. *Dent Mater.* 2014 Dec; 30(12):1291-303.
68. Keskin C, Demiryurek EO, Ozyurek T. Color Stabilities of Calcium Silicate-based Materials in Contact with Different Irrigation Solutions. *J Endod.* 2015 Mar;41(3):409-11.
69. Grech L, Mallia B, Camilleri J. Characterization of set Intermediate Restorative Material, Biodentine, Bioaggregate and a prototype calcium silicate cement for use as root-end filling materials. *Int Endod J.* 2013 Jul; 46(7):632-41.
70. Han L, Okiji T. Uptake of calcium and silicon released from calcium silicate-based endodontic materials into root canal dentine. *Int Endod J.* 2011 Dec;44(12):1081-7.
71. Atmeh AR, Chong EZ, Richard G, Festy F, Watson TF. Dentin-cement Interfacial Interaction Calcium Silicates and Polyalkenoates. *J Dent Res.* 2012 May; 91(5):454-9.
72. Guneser MB, Akbulut MB, Eldeniz AU. Effect of various endodontic irrigants on the push-out bond strength of biodentine and conventional root perforation repair materials. *J Endod.* 2013 Mar; 39(3):380-4.
73. Leiendecker AP, Qi YP, Sawyer AN, Niu LN, Agee KA, Loushine RJ, et al. Effects of Calcium Silicate-based Materials on Collagen Matrix Integrity of Mineralized Dentin. *J Endod.* 2012 Jun; 38(6):829-33.
74. Marconyak LJ Jr, Kirkpatrick TC, Roberts HW, Roberts MD, Aparicio A, Himel VT, et al. A Comparison of Coronal Tooth Discoloration Elicited by Various Endodontic Reparative Materials. *J Endod.* 2016 Mar;42(3):470-3.
75. Shokouhinejad N, Nekoofar MH, Pirmoazen S, Shamshiri AR, Dummer PM. Evaluation and

- Comparison of Occurrence of Tooth Discoloration after the Application of Various Calcium Silicate-based Cements: An Ex Vivo Study. *J Endod.* 2016 Jan; 42(1):140-4.
76. Nowicka A, Lipski M, Parafiniuk M, Sporniak-Tutak K, Lichota D, Kosierkiewicz A, et al. Response of human dental pulp capped with biodentine and mineral trioxide aggregate. *J Endod.* 2013 Jun; 39(6):743-7.
77. Bani M, Sungurtekin-Ekçi E, Odabaş ME. Efficacy of Biodentine as an Apical Plug in Nonvital Permanent Teeth with Open Apices: An In Vitro Study. *Biomed Res Int.* 2015; 2015: 359275. doi: 10.1155/2015/359275. Epub 2015 Sep; 7.
78. Tanalp J, Karapınar-Kazandağ M, Dölekoğlu S, Kayahan MB. Comparison of the radiopacities of different root-end filling and repair materials. *ScientificWorldJournal.* 2013 Oct;2013:594950.
79. Caron G, Azérad J, Faure MO, Machtou P, Boucher Y. Use of a new retrograde filling material (Biodentine) for endodontic surgery: two case reports. *Int J Oral Sci.* 2014 Dec; 6(4):250-3.
80. Asgary S, Shahabi S, Jafarzadeh T, Amini S, Kheirieh S. The properties of a new endodontic material. *J Endod.* 2008 Aug;34(8):990-3.
81. Amini Ghazvini S, Abdo Tabrizi M, Kobarfard F, Akbarzadeh Baghban A, Asgary S.. Ion release and pH of a new endodontic cement, MTA and Portland cement. *Iran Endod J.* 2009 Spring; 4(2): 74-78.
82. Torabzadeh H, Aslanzadeh S, Asgary S. Radiopacity of Various Dental Biomaterials. *Research J of Biological Sci.* 2012;7(4):152-8.
83. Asgary S, Eghbal MJ, Parirokh M, Ghoddusi J. Effect of two storage solutions on surface topography of two root-end fillings. *Aust Endod J.* 2009 Dec; 35(3):147-52.
84. Asgary S, Kamrani F, Taheri S. Evaluation of antimicrobial effect of MTA, calcium hydroxide, and CEM cement. *Iran Endod J.* 2007 Fall; 2(3): 105-109.
85. Kangarlou A, Sofiabadi S, Yadegari Z, Asgary S. Antifungal effect of calcium enriched mixture cement against *Candida albicans*. *Iran Endod J.* 2009 Summer; 4(3):101-105.
86. Asgary S, Eghbal MJ, Parirokh M, Torabzadeh H. Sealing ability of three commercial mineral trioxide aggregates and an experimental root-end filling material. *Iran Endod J.* 2006 Fall; 1(3):101-105.
87. Asgary S, Eghbal MJ, Parirokh M. Sealing ability of a novel endodontic cement as a root-end filling material. *J Biomed Mater Res A.* 2008 Dec 1;87(3):706-9.
88. Hasheminia M, Nejad SL, Asgary S. Sealing ability of MTA and CEM cement as root-end fillings of human teeth in dry, saliva or blood-contaminated conditions. *Iran Endod J.* 2010 Autumn; 5(4):151-156.
89. Nosrat A, Seifi A, Asgary S. Pulpotomy in caries-exposed immature permanent molars using calcium-enriched mixture cement or mineral trioxide aggregate: a randomized clinical trial. *Int J Paediatr Dent.* 2013 Jan; 23(1):56-63.
90. Asgary S, Eghbal MJ. The effect of pulpotomy using a calcium-enriched mixture cement versus one-visit root canal therapy on postoperative pain relief in irreversible pulpitis: a randomized clinical trial. *Odontology.* 2010 Jul;98(2):126-33.
91. Ghajari MF, Jeddi TA, Iri S, Asgary S. Direct pulp-capping with calcium enriched mixture in primary molar teeth: a randomized clinical trial. *Iran Endod J.* 2010 Winter; 5(1):27-30.
92. Asgary S. Furcal perforation repair using calcium enriched mixture cement. *J Conserv Dent.* 2010 Jul-Sep; 13(3):156-158.
93. Asgary S, Nosrat A, Seifi A. Management of inflammatory external root resorption by using calcium-enriched mixture cement: a case report. *J Endod.* 2011 Mar;37(3):411-3.
94. Asgary S, Eghbal MJ, Ehsani S. Periradicular regeneration after endodontic surgery with calcium-enriched mixture cement in dogs. *J Endod.* 2010 May;36(5):837-41.
95. Nosrat A, Seifi A, Asgary S. Regenerative endodontic treatment (revascularization) for necrotic immature permanent molars: a review and report of two cases with a new biomaterial. *J Endod.* 2011 Apr; 37(4):562-7.
96. Asgary S, Eghbal MJ. Treatment outcomes of pulpotomy in permanent molars with irreversible pulpitis using biomaterials: a multi-center randomized controlled trial. *Acta Odontol Scand.* 2013 Jan;71(1):130-6.
97. Asgary S, Eghbal MJ, Ghoddusi J, Yazdani S. One-year results of vital pulp therapy in permanent molars with irreversible pulpitis: an ongoing multicenter, randomized, non-inferiority clinical trial. *Clin Oral Investig.* 2013 Mar;17(2):431-9.
98. Damas BA, Wheeler MA, Bringas JS, Hoen MM. Cytotoxicity comparison of mineral trioxide

- aggregates and EndoSequence bioceramic root repair materials. *J Endod.* 2011 Mar;37(3):372-5.
99. Shokouhinejad N, Nekoofar MH, Razmi H, Sajadi S, Davies TE, Saghiri M, et al. Bioactivity of EndoSequence root repair material and bioaggregate. *Int Endod J.* 2012 Dec; 45(12):1127-34.
100. Hansen SW, Marshall JG, Sedgley CM. Comparison of intracanal EndoSequence Root Repair Material and ProRoot MTA to induce pH changes in simulated root resorption defects over 4 weeks in matched pairs of human teeth. *J Endod.* 2011 Apr; 37(4):502-6.
101. Lovato KF, Sedgley CM. Antibacterial activity of endosequence root repair material and proroot MTA against clinical isolates of *Enterococcus faecalis*. *J of Endod.* 2011 Nov; 37(11):1542-6.
102. Wang Z, Ma J, Shen Y, Haapasalo M. Acidic pH weakens the microhardness and microstructure of three tricalcium silicate materials. *Int Endod J.* 2015 Apr; 48(4):323-32.
103. Modareszadeh MR, Di Fiore PM, Tipton DA, Salamat N. Cytotoxicity and alkaline phosphatase activity evaluation of endosequence root repair material. *J Endod.* 2012 Aug; 38(8):1101-5.
104. Machado J, Johnson JD, Paranjpe A. The Effects of Endosequence Root Repair Material on Differentiation of Dental Pulp Cells. *J Endod.* 2016 Jan; 42(1):101-105.
105. Chen I, Karabucak B, Wang C, Wang HG, Koyama E, Kohli MR, et al. Healing after Root-end Microsurgery by Using Mineral Trioxide Aggregate and a New Calcium Silicate-based Bioceramic Material as Root-end Filling Materials in Dogs. *J Endod.* 2015 Mar; 41(3):389-99.
106. Khalil WA, Abunasef SK. Can Mineral Trioxide Aggregate and Nanoparticulate EndoSequence Root Repair Material Produce Injurious Effects to Rat Subcutaneous Tissues? *J Endod.* 2015 Jul;41(7):1151-1156.
107. Beatty H, Svec T. Quantifying Coronal Tooth Discoloration Caused by Biodentine and EndoSequence Root Repair Material. *J Endod.* 2015 Dec; 41(12):2036-9.
108. Jiang Y, Zheng Q, Zhou X, Gao Y, Huang D. A comparative study on root canal repair materials: a cytocompatibility assessment in L929 and MG63 cells. *ScientificWorldJournal.* 2014 Jan; 2014:463826.
109. Shi S, Bao ZF, Liu Y, Zhang DD, Chen X, Jiang LM, et al. Comparison of in vivo dental pulp responses to capping with iRoot BP Plus and mineral trioxide aggregate. *Int Endod J.* 2016 Feb; 49(2):154-160.
110. De-Deus G, Canabarro A, Alves GG, Marins JR, Linhares AB, Granjeiro J. Cytocompatibility of the ready-to-use bioceramic putty repair cement iRoot BP Plus with primary human osteoblasts. *Int Endod J.* 2012 Jun;45(6):508-13.
111. Hess D, Solomon E, Spears R, He J. Retreatability of a bioceramic root canal sealing material. *J Endod.* 2011 Nov;37(11):1547-9.
112. Zhang W, Li Z, Peng B. Assessment of a new root canal sealer's apical sealing ability. *Oral Surg Oral Med Oral Pathol Oral Radiol and Endod.* 2009 Jun; 107(6):e79-e82.
113. Nagas E, Uyanik MO, Eymirli A, Cehreli ZC, Vallittu PK, Lassila LV, et al. Dentin moisture conditions affect the adhesion of root canal sealers. *J of Endod.* 2012 Feb;38(2):240-4.
114. Shokouhinejad N, Gorjestani H, Nasseh AA, Hoseini A, Mohammadi M, Shamshiri AR. Push-out bond strength of gutta-percha with a new bioceramic sealer in the presence or absence of smear layer. *Aust Endod J.* 2013 Dec; 39(3):102-6.
115. Ersahan S, Aydin C. Dislocation resistance of iRoot SP, a calcium silicate-based sealer, from radicular dentine. *J Endod.* 2010 Dec; 36(12):2000-2.
116. Amin SA, Seyam RS, El-Samman MA. The effect of prior calcium hydroxide intracanal placement on the bond strength of two calcium silicate-based and an epoxy resin-based endodontic sealer. *J Endod.* 2012 May; 38(5):696-9.
117. Shokouhinejad N, Hoseini A, Gorjestani H, Raoof M, Assadian H, Shamshiri AR. Effect of phosphate-buffered saline on push-out bond strength of a new bioceramic sealer to root canal dentin. *Dent Res J (Isfahan).* 2012 Sept; 9(5):595-599.
118. Zhang H, Shen Y, Ruse ND, Haapasalo M. Antibacterial activity of endodontic sealers by modified direct contact test against *Enterococcus faecalis*. *J Endod.* 2009 Jul;35(7):1051-5.
119. Loushine BA, Bryan TE, Looney SW, Gillen BM, Loushine RJ, Weller RN, et al. Setting properties and cytotoxicity evaluation of a premixed bioceramic root canal sealer. *J Endod.*

2011 May;37(5):673-7.

120. Borges RP, Sousa-Neto MD, Versiani MA, Rached-Júnior FA, De-Deus G, Miranda CE, et al. Changes in the surface of four calcium silicate-containing endodontic materials and an epoxy resin-based sealer after a solubility test. *Int Endod J*. 2012 May; 45(5):419-28.

121. Ersahan S, Aydin C. Solubility and apical sealing characteristics of a new calcium silicate-based root canal sealer in comparison to calcium hydroxide-, methacrylate resin-and epoxy resin-based sealers. *Acta Odontol Scand*. 2013 May-Jul; 71(3-4):857-62.

122. Zhang W, Li Z, Peng B. Effects of iRoot SP on mineralization-related genes expression in MG63 cells. *J Endod*. 2010 Dec;36(12):1978-82.

123. Zhang W, Peng B. Tissue reactions after subcutaneous and intraosseous implantation of iRoot SP, MTA and AH Plus. *Dent Mater J*. 2015; 34(6):774-80.

124. Silva EJ, Rosa TP, Herrera DR, Jacinto RC, Gomes BP, Zaia AA. Evaluation of cytotoxicity and physicochemical properties of calcium silicate-based endodontic sealer MTA Fillapex. *J Endod*. 2013 Feb; 39(2):274-7.

125. Bin CV, Valera MC, Camargo SE, Rabelo SB, Silva GO, Balducci I, et al. Cytotoxicity and genotoxicity of root canal sealers based on mineral trioxide aggregate. *J Endod*. 2012 Apr; 38(4):495-500.

126. Faria-Júnior NB, Tanomaru-Filho M, Berbert FL, Guerreiro-Tanomaru JM. Antibiofilm activity, pH and solubility of endodontic sealers. *Int Endod J*. 2013 Aug;46(8):755-62.

127. Morgental RD, Vier-Pelisser FV, Oliveira SD, Antunes FC, Cogo DM, Kopper P. Antibacterial activity of two MTA-based root canal sealers. *Int Endod J*. 2011 Dec; 44(12):1128-33.

128. Sagsen B, Ustün Y, Demirbuga S, Pala K. Push-out bond strength of two new calcium

silicate-based endodontic sealers to root canal dentine. *Int Endod J*. 2011 Dec; 44(12):1088-91.

129. Bidar M, Sadeghhalhoseini N, Forghani M, Attaran N. Effect of the smear layer on apical seals produced by two calcium silicate-based endodontic sealers. *J Oral Sci*. 2014 Sept; 56(3):215-9.

130. Sağsen B, Ustün Y, Pala K, Demirbuğa S. Resistance to fracture of roots filled with different sealers. *Dent Mater J*. 2012;31(4):528-32.

131. Borges ÁH, Orçati Dorileo MC, Dalla Villa R, Borba AM, Semenoff TA, Guedes OA, et al. Physicochemical properties and surfaces morphologies evaluation of MTA FillApex and AH Plus. *ScientificWorldJournal*. 2014; 2014: 589732.

132. Nikhil V, Bansal P, Sawani S. Effect of technique of sealer agitation on percentage and depth of MTA Fillapex sealer penetration: A comparative in-vitro study. *J Conserv Dent*. 2015 Mar-Apr; 18(2):119-123.

133. Kok D, Rosa RA, Barreto MS, Busanello FH, Santini MF, Pereira JR, et al. Penetrability of AH plus and MTA fillapex after endodontic treatment and retreatment: A confocal laser scanning microscopy study. *Microsc Res Tech*. 2014 Jun; 77(6):467-71.

134. Bósio CC, Felipe GS, Bortoluzzi EA, Felipe MC, Felipe WT, Rivero ER. Subcutaneous connective tissue reactions to iRoot SP, mineral trioxide aggregate (MTA) Fillapex, DiaRoot BioAggregate and MTA. *Int Endod J*. 2014 Jul; 47(7):667-74.

135. Zhou HM, Du TF, Shen Y, Wang ZJ, Zheng YF, Haapasalo M. In Vitro Cytotoxicity of Calcium Silicate-containing Endodontic Sealers. *J Endod*. 2015 Jan;41(1):56-61.

136. Assmann E, Böttcher DE, Hoppe CB, Grecca FS, Kopper PM. Evaluation of bone tissue response to a sealer containing mineral trioxide aggregate. *J Endod*. 2015 Jan; 41(1):62-6.