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The use of bioceramic root canal sealers for obturation of the root canal system: A review

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Abstract

The use of bioceramic root canal sealers in endodontics is a promising approach because of the advantages such as improved flow properties, biocompatible and could promote the formation of hard tissue. Due to the recent technology and limited scientific evidence, the effectiveness of bioceramic root canal sealers remains unclear. This article focuses on the physicochemical properties, biocompatibility, biomineralisation, retreatability, 3D obturation and current practice of using bioceramic root canal sealers. The relevant articles for this review were searched manually from Google Scholar and PubMed using keywords 'bioceramic root filling material AND endodontics', 'bioceramic root canal sealers AND endodontics', 'cytotoxicity AND bioceramic root canal sealers', 'bioceramic root canal sealers AND physicochemical properties', 'biomineralisation AND bioceramic root canal sealers' and 'retreatment efficacy AND bioceramic root filling materials'. Since the clinical data concerning the obturation with bioceramic root canal sealers is lacking, the selection of materials should be made based on the available scientific evidence, individual cases, material availability and operator's preference.

Keywords: *bioceramic root canal sealers, cytotoxicity, biomineralisation, physicochemical properties*

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Introduction

The use of bioceramic root canal sealers for obturation of the root canal system has been a subject of interest in the recent years. However, whether this material can provide an effective sealing of the complex root canal anatomy remains unclear due to the limited scientific evidence. The obturation of root canal system can be performed using a conventional technique with a combination of gutta-percha and root canal sealer, or thermoplastic technique. The goal standard of root canal sealers for obturating of the root canal system should have low porosity and solubility, adequate setting time and ability to promote hard tissue formation (Gandolfi and Prati, 2010).

Currently, there is a move towards using bioceramic root canal sealers such as MTA Fillapex, GuttaFlow Bioseal, iRoot SP root canal sealer, CeraSeal Bioceramic root canal sealer and others. Generally, the properties of root canal sealers are determined by the type and ratio of the main components, thus enabling them to function effectively under clinical situations (Zhou *et al*., 2013). For instance, bioceramic root canal sealers usually contain calcium silicate and/or calcium phosphate, have a higher pH value, chemically stable, lack of shrinkage and biocompatible, making them favourable root canal sealers (Zhou *et al*., 2013).

In general, bioceramics can be categorised into bioinert, bioactive and bioresorbable based on their interactivity with the surrounding tissues (Best *et al*., 2008; Wang *et al*., 2019). Bioinert ceramics such as alumina and zirconia are well-tolerated by the tissue, triggering no toxic response, whereas bioactive ceramics such as ceramics, glasses, glass-ceramics can interact and form a direct bond with the tissue (Best *et al*., 2008) through the formation of hydroxyapatite layer as the interfacial bonding (De Aza *et al*., 2007; Vollenweider *et al*., 2007). This layer has a similar chemical constituent and structure to the inorganic component of bone (De Aza *et al*., 2007; Best *et al*., 2008). The bioresorbable ceramics such as tricalcium phosphate and calcium sulphate will be replaced or incorporated into the hard tissue to become part of the structure (Raghavendra *et al*., 2017).

Mineral trioxide aggregate (MTA) is the first generation of bioceramic (Haapasalo *et al*., 2015; Assadian *et al*., 2016; Raghavendra *et al*., 2017; Song *et al*., 2020), introduced by Dr. Mahmoud Torabinejad and is composed of tricalcium silicate, tricalcium aluminate, tricalcium oxide, and silicate oxide with the addition of bismuth oxide to make the material radiopaque (Torabinejad *et al*., 1995). This material is usually used in surgical endodontics, apexification, perforation repairs and pulpotomies (Torabinejad and Chivian, 1999). MTA is known to have excellent properties such as biocompatible, osteoconductive and osteoinductive (Raghavendra *et al*., 2017), hence making it suitable for various endodontic procedures. The limitations of MTA are its handling characteristics, discolouration due to the iron compounds and require longer setting time.

Bioceramic root canal sealers are the new generation with the advantages of being well-tolerated by the host tissue, able to promote hard tissue formation and has antimicrobial properties (Raghavendra *et al*., 2017) but at this stage, robust scientific evidence on this material is limited. The example of bioceramic root canal sealers that have been introduced into the market include EndoSequence BC Sealer (Brasseler, Savannah, GA, USA) or iRoot SP root canal sealer (Innovative BioCreamix Inc, Vancouver, Canada), MTA Fillapex (Angelus, Londrina, Brazil), Endoseal MTA (Maruchi, Wonju, Korea), Tech Biosealer Endo (Isasan, Como, Italy), CeraSeal Bioceramic root canal sealer (Meta Biomed CO. LTD, Korea), Sankin Apatite root canal sealer (Sankin-kogyo, Tokyo, Japan), GuttaFlow Bioseal (Colténe/Whaledent AG, Altstatten, Switzerland), BioRoot™ RCS (Septodent, Saint Maur Des Fosses, France), TotalFill BC sealer (FKG Dentaire, La Chaux-de-Fonds, Switzerland), Sealer Plus BC (MK Life Produtos Medical e Dental, Porto Alegre, Brazil), Smartpaste Bio® (CRD Ltd, Stamford, UK) and others.

Physicochemical properties

The American National Standards Institute/American Dental Association (ANSI/ADA) Specifications number 57 set the standards and tests for the physicochemical properties of root canal sealer. This includes setting time, flowability, solubility, radiopacity, film thickness, and dimensional stability. Some studies on the physicochemical properties of bioceramic root canal sealers have been conducted according to these specifications (Vidotto *et al*., 2011; Borges *et al*., 2014; Camargo *et al*., 2017; Lee *et al*., 2017; Poggio *et al*., 2017; Colombo *et al*., 2018; Khalil *et al*., 2019), although other researchers have used the International Organisation for Standardisation (ISO) 6876 specifications (Gandolfi and Prati, 2010; de Miranda Candeiro *et al*., 2012; Vitti *et al*., 2013; Zhou *et al*., 2013; Lim *et al*., 2015; Agarwal and

Nikhil, 2016; Lee *et al*., 2017; Poggio *et al*., 2017; Tanomaru-Filho *et al.*, 2017; Colombo *et al*., 2018; Mendes *et al*., 2018; Zordan-Bronzel *et al*., 2019; Kharouf *et al*., 2020). The ASTM standards C266-07 and C373-88 have also been used to evaluate the setting time and solubility respectively (Gandolfi and Prati, 2010). The summary of physicochemical properties of some bioceramic root canal sealers are shown in Table 1.

Setting time

ANSI/ADA Specifications 57 recommends that all root canal sealers should have a setting time of no greater than 10% of the time determined by the manufacturer. In the studies by (Zhou *et al*., 2013; Camargo *et al*., 2017; Lee *et al*., 2017; Tanomaru-Filho *et al.*, 2017; Zordan-Bronzel *et al*., 2019), a Gilmore needle was probed onto the surface of root canal sealers and the setting time was recorded when the indenter needle failed to create the indentation. The results revealed that GuttaFlow Bioseal met these specifications (Camargo *et al*., 2017; Tanomaru-Filho *et al.*, 2017) but in other studies, the TotalFill BC sealer (Zordan-Bronzel *et al*., 2019), EndoSequence BC Sealer, EndoSeal MTA and MTA Fillapex (Lee *et al*., 2017) did not fulfil the ISO specifications.

Dimensional stability

ANSI/ADA Specifications 57 recommends that root canal sealers should not exceed 1 % contraction or 0.1 % expansion. In the studies by (Camargo *et al*., 2017; Zhou *et al*., 2013), the percentage of the dimensional alterations was calculated after 30 days following the complete setting of the materials and the results showed that GuttaFlow Bioseal (Camargo *et al*., 2017) did not meet these specifications. However, the MTA Fillapex and EndoSequence BC Sealer fulfilled the ISO specifications (Zhou *et al*., 2013).

Solubility

The solubility of material is the percentage of mass loss compared to the initial mass (Borges *et al*., 2014). ANSI/ADA Specifications 57 and ISO specifications recommend that an ideal root canal sealer should lose not more than 3% of its mass after immersion in water for 24 hours. MTA Fillapex (Vitti *et al*., 2013; Zhou *et al*., 2013; Borges *et al*., 2014; Poggio *et al*., 2017; Colombo *et al*., 2018) and GuttaFlow Bioseal (Khalil *et al*., 2019) fulfilled these specifications. However, BioRoot™ RCS and TotalFill BC sealer did not comply with the ANSI/ADA Specifications 57 and ISO specifications (Poggio *et al*., 2017; Colombo *et al*., 2018). Sealer Plus BC (Mendes *et al*., 2018) and CeraSeal Bioceramic root canal sealer (Kharouf *et al*., 2020) also did not fulfil the ISO specifications, whereby the solubility of these materials were higher than the recommended values. Although the solubility of the Endosequence BC Sealer fulfilled the ISO 6876 specifications, it approached close to the maximum value for solubility (Zhou *et al*., 2013).

Table 1. Physicochemical properties of bioceramic root canal sealers

Physicochemical properties	Materials	Specifications	Fulfilment	References
Setting time	GuttaFlow Bioseal	ANSI/ADA Specifications 57, ISO 6876 specifications	Yes	(Camargo *et al*., 2017); Tanomaru-Filho *et al.*, 2017)
	EndoSequence BC Sealer	ISO 6876 specifications	No	(Lee *et al*., 2017)
	EndoSeal MTA			
	MTA Fillapex			
	TotalFill BC sealer			(Zordan-Bronzel *et al*., 2019)

Table 1 (continued). Physicochemical properties of bioceramic root canal sealers

Physicochemical properties	Materials	Specifications	Fulfilment	References
Dimensional stability	GuttaFlow Bioseal	ANSI/ADA Specifications 57	No	(Camargo *et al.*, 2017)
	EndoSequence BC Sealer	ISO 6876 specifications	Yes	(Zhou *et al.*, 2013)
	MTA Fillapex			
Solubility	GuttaFlow Bioseal	ANSI/ADA Specifications 57, ISO 6876 specifications	Yes	(Khalil *et al.*, 2019)
	MTA Fillapex		Yes	(Vitti *et al.*, 2013; Zhou *et al.*, 2013; Borges *et al.*, 2014; Poggio *et al.*, 2017; Colombo *et al.*, 2018)
	BioRoot™ RCS		No	(Poggio *et al.*, 2017; Colombo *et al.*, 2018)
	TotalFill BC sealer		No	(Poggio *et al.*, 2017; Colombo *et al.*, 2018; (Zordan-Bronzel *et al.*, 2019)
	Sealer Plus BC	ISO 6876 specifications	No	(Mendes *et al.*, 2018)
	Endosequence BC Sealer		Yes	(Zhou *et al.*, 2013)
	CeraSeal Bioceramic root canal sealer		No	(Kharouf *et al.*, 2020)
Flowability	GuttaFlow Bioseal	ANSI/ADA Specifications 57	No	(Camargo *et al.*, 2017)
	MTA Fillapex	ISO 6876 specifications	Yes	(Vitti *et al.*, 2013; Zhou *et al.*, 2013; Lee *et al.*, 2017)
	EndoSeal MTA			
	EndoSequence BC Sealer		Yes	(de Miranda Candeiro *et al.*, 2012; Zhou *et al.*, 2013; Agarwal and Nikhil, 2016)
			No	(Lee *et al.*, 2017)
	BioRoot™ RCS		Yes	(Kharouf *et al.*, 2020)
	CeraSeal Bioceramic root canal sealer		No	
Radiopacity	GuttaFlow Bioseal	ANSI/ADA Specification 57	Yes	(Camargo *et al.*, 2017)
		ISO 6876 specifications	Yes	(Tanomaru-Filho *et al.*, 2017)
	MTA Fillapex	ANSI/ADA Specifications 57	Yes	(Vidotto *et al.*, 2011 Borges *et al.*, 2014)
		ISO 6876 specifications	Yes	(Lee *et al.*, 2017)
	TotalFill BC sealer			(Tanomaru-Filho *et al.*, 2017; Zordan-Bronzel *et al.*, 2019)
	EndoSequence BC Sealer			(de Miranda Candeiro *et al.*, 2012; Agarwal and Nikhil, 2016; Lee *et al.*, 2017)
	EndoSeal MTA			(Lim *et al.*, 2015; Lee *et al.*, 2017)

Flowability

ANSI/ADA Specifications 57 recommends that root canal sealers diameter should be greater than 20 mm. GuttaFlow Bioseal (Camargo *et al*., 2017) did not meet these specifications. MTA Fillapex (Vitti *et al*., 2013; Zhou *et al*., 2013; Lee *et al*., 2017) and EndoSeal MTA (Lee *et al*., 2017) both met the ISO specifications. However, EndoSequence BC Sealer showed conflicting results where some studies indicate its diameter to be in accordance with the ISO specifications (de Miranda Candeiro *et al*., 2012; Zhou *et al*., 2013; Agarwal and Nikhil, 2016), while a study by (Lee *et al.*, 2017) indicated otherwise.

pH values

High pH values is important for root canal sealers because the release of calcium ions not only stimulates hard tissue formation but also triggers antibacterial activity (Al-Haddad and Che Ab Aziz, 2016) as reported in the studies by (Colombo *et al*., 2018; Kharouf *et al*., 2020). BioRoot™ RCS (Colombo *et al*., 2018; Kharouf *et al*., 2020) and TotalFill BC sealer (Colombo *et al*., 2018) exhibited high alkaline pH (up to 11) at 24 hours, similar to the previous studies on EndoSequence BC Sealer, EndoSeal MTA and MTA Fillapex (Lee *et al.*, 2017). High alkalinity of EndoSeal MTA (Lim *et al.*, 2015) and CeraSeal Bioceramic root canal sealer (Kharouf *et al*., 2020) have also been reported.

Radiopacity

ANSI/ADA Specifications 57 and ISO 6876 specifications recommend that all root canal sealers must have radiopacity greater than or equal to 3 mm Al. GuttaFlow Bioseal (Camargo *et al*., 2017) complied with the ANSI/ADA Specification 57, as well as the ISO 6876 specifications (Tanomaru-Filho *et al*., 2017), similar with MTA Fillapex that fulfilled the ANSI/ADA Specifications 57 (Vidotto *et al*., 2011), (Borges *et al*., 2014) and ISO 6876 specifications (Lee *et al*., 2017). TotalFill BC sealer (Tanomaru-Filho *et al*., 2017), EndoSequence BC Sealer (de Miranda Candeiro *et al*., 2012; Agarwal and Nikhil, 2016; Lee *et al*., 2017) and EndoSeal MTA (Lim *et al*., 2015; Lee *et al*., 2017) were also in accordance with the ISO 6876 specifications.

Cytotoxicity

Cytotoxic analysis of bioceramic root canal sealers have been reported by many researchers (Loushine *et al*., 2011; Mukhtar-Fayyad, 2011; Silva *et al*., 2013; Yoshino *et al*., 2013; Chang *et al*., 2014; Baraba *et al*., 2016; Candeiro *et al*., 2016; Silva *et al*., 2016; Collado-González *et al*., 2017; Saygili *et al*., 2017; Victoria-Escandell *et al*., 2017; Benetti *et al*., 2019; Rodríguez-Lozano *et al*., 2019).

The findings on viability of cells observed in their studies was complex, could be associated with multiple factors such as the types of root canal sealers (Loushine *et al*., 2011; Silva *et al*., 2013; Candeiro *et al*., 2016; Baraba *et al*., 2016; Collado-González *et al*., 2017; Saygili *et al*., 2017; Rodríguez-Lozano *et al*., 2019), incubation periods (Bryan *et al*., 2010; Loushine *et al*., 2011; Silva *et al*., 2013) and concentration of the root canal in the extract solution (Bryan *et al*., 2010; Mukhtar-Fayyad, 2011; Yoshino *et al*., 2013; Benetti *et al.*, 2019).

For example, the cytotoxic effects of Endosequence BC Sealer (Baraba *et al*., 2016; Giacomino *et al*., 2019) or iRoot SP root canal sealer (Mukhtar-Fayyad, 2011) have been reported but the findings were inconsistent in other study where the iRoot SP root canal sealer and MTA Fillapex showed no cytotoxic effects (Chang *et al.*, 2014). The discrepancy between these findings could be attributed to the different types of cell cultures and methods used for evaluating the viability of cells. Despite this, it is suggested by many researchers that the chemical composition of MTA Fillapex which includes salicylate resin, diluting resin and silica (Silva *et al*., 2013; Baraba *et al*., 2016; Silva *et al*., 2016; Victoria-Escandell et al., 2017; Colombo *et al*., 2018) that could contribute to the cytotoxic effects.

Another aspect was the high pH value of MTA Fillapex and Endosequence BC Sealer

(Baraba *et al*., 2016) that was postulated to cause loss of cell viability and membrane integrity (Lee *et al*., 2017). Bioceramic root canal sealers that exhibit prolonged high pH value (up to 12) before its setting may also cause damage to the periapical tissue. This needs to be carefully considered when choosing bioceramic root canal sealers for obturating the root canal, despite the materials' osteogenic and antimicrobial properties (Lee *et al*., 2017).

In addition to that, the high solubility of MTA Fillapex that leads to a higher release of the toxic components (Silva *et al*., 2016) and long setting time of Endosequence BC Sealer (Baraba *et al*., 2016) can be the contributing factors determining the viability of cells.

Regarding the influence of concentration of the root canal sealers in the extract solution, most concentrated extract leads to more cell damage compared to a more diluted concentration (Mukhtar-Fayyad, 2011; Yoshino *et al*., 2013; Benetti *et al*., 2019) and this might occur because of the high pH of the materials that causes damage to the adjacent cells and denatures proteins (Siqueira Jr and Lopes, 1999). For instance, pure extract of MTA Fillapex showed high toxicity levels throughout the incubation periods from 24 to 72 hours as measured by occurrence of cell death and alteration of cell growth rates (Yoshino *et al*., 2013). However, a decreased cytotoxic levels were observed in diluted MTA Fillapex (Yoshino *et al*., 2013) and Sealer Plus BC (Benetti *et al*., 2019). These findings showed that eluents from the root canal sealers were cytotoxic to the cell culture and dependent on its concentration (Bryan *et al*., 2010).

The incubation period could also be involved in determining the viability of cells. Perhaps, this might explain why the severe cytotoxicity could be observed at 24 hours regardless of any root canal sealers (Bryan *et al*., 2010; Loushine *et al*., 2011) but the findings were contradictory to the other study where no cytotoxicity was observed in BioRoot™ RCS and TotalFill BC sealer observed at 24 hours (Colombo *et al*., 2018). This could be due to the different types of cell cultures that might not response similarly despite similar incubation periods. Freshly mixed AH Plus root canal sealer was cytotoxic, but the cytotoxicity gradually decreased over time (Bryan *et al*., 2010 Loushine *et al*., 2011; Silva *et al*., 2013). However, the MTA Fillapex exhibited cytotoxicity throughout the incubation periods (Silva *et al*., 2013; Baraba *et al*., 2016). Despite no cytotoxic effect in BioRoot™ RCS and TotalFill BC sealer during the early incubation period, mild cytotoxicity was exhibited at later incubation periods (48 hours and 72 hours) (Colombo *et al*., 2018).

Previous studies on the material cytotoxicity were carried out using *in vitro* cell cultures under specific protocols. However, results from this approach were limited because the cell cultures were monoclonal in origin, not dynamic in nature, had no cell-cell interactions and did not accurately represent the real clinical situation (Loushine *et al*., 2011). Additionally, the cell culture does not contain mechanisms for removal of the irritants (Bryan *et al*., 2010). Root canal sealers showed high cytotoxicity in a 2 dimensional (D) cell culture compared to the 3D cell culture due to the absence of cell-cell interactions in the 2D cell culture and a reduced capability of the extracts of root canal sealers to penetrate the 3D cell culture (Silva *et al*., 2016). Therefore, the findings of *in vitro* studies must be carefully interpreted and the extrapolation to the clinical practice must be made with great caution.

In order to confirm the safety and effectiveness of bioceramic root canal sealers, an alternative approach through an *in vivo* technique using Wistar rats was introduced to assess the histological characteristics of subcutaneous tissues after implantation with the materials (Bueno *et al*., 2016; Santos *et al*., 2019). It was found that the GuttaFlow Bioseal triggered low inflammatory reactions during the early and late stages of observation and improved vascular changes during late assessment (Santos *et al*., 2019). However, mild-to-moderate inflammatory reactions were observed during the initial observation period when using Smartpaste Bio®, but this subsequently decreased over time (Bueno *et al*., 2016).

It has been demonstrated that the cytotoxicity of a root canal sealers may decrease with time (Loushine *et al*., 2011; Silva *et al*., 2013; Bueno *et al*., 2016) and later become noncytotoxic, achieved by desorption of the toxic components into the surrounding tissue (Bryan *et al*., 2010). Although the toxic components may take time to diffuse away from the periapical tissue, their presence may delay the healing process of periapical inflammation (Bryan *et al*., 2010), therefore, it is essential to understand that this desorption is immune response and can cause ongoing inflammatory process (Giacomino *et al*., 2019).

Biomineralisation

The osteogenic potential of bioceramic root canal sealers, also known as the biomineralisation have been reported in the previous studies (Gandolfi *et al*., 2008; Bryan *et al*., 2010; Han and Okiji, 2013; Chang *et al*., 2014; Hoikkala *et al*., 2018; Giacomino *et al*., 2019). This process begins with the release of calcium ions from the materials followed by the formation of silicate hydroxyl (Si-OH) groups at the material's surface, this will act as an ideal site for nucleation of hydroxyapatite crystal which later precipitates the formation of amorphous layer and becomes crystallised into carbonated hydroxyapatite (Hoikkala *et al*., 2018). It has been demonstrated that the MTA Fillapex (Chang *et al*., 2014) Smartpaste Bio® (Bueno *et al*., 2016), GuttaFlow Bioseal (Hoikkala *et al*., 2018), iRoot SP (Chang *et al*., 2014) or EndoSequence BC Sealer (Giacomino *et al*., 2019; Seo *et al*., 2019), BioRoot™ RCS (Seo *et al*., 2019), EndoSeal MTA (Seo *et al*., 2019) and ProRoot® ES endodontic root canal sealer (Giacomino *et al*., 2019) showed mineralisation activity in the cultured cell models.

Retreatability

Data on the retreatability of bioceramic root canal sealers has been reported in many studies (Hess *et al*., 2011; Kim *et al*., 2015; de Siqueira Zuolo *et al*., 2016; Oltra *et al*., 2017; Donnermeyer *et al*., 2018; Kim *et al*., 2019; Kontogiannis *et al*., 2019; Romeiro *et al*., 2020). Even though there are similarities in some of their findings, other aspects are inconsistent, could be attributed to the use of different retreatment rotary file systems, type of the extracted teeth and bioceramic root canal sealers. Research on retreatability focuses on the amount of remnants and the duration of time required for the procedure.

For instance, after the removal of root canal sealer from the root canal, MTA Fillapex (Uzunoglu *et al*., 2015), iRoot SP (Uzunoglu *et al*., 2015) or EndoSequence BC Sealer was demonstrated to leave more remnants (de Siqueira Zuolo *et al*., 2016; Oltra *et al*., 2017; Kim *et al*., 2019) and require longer retreatment time (Hess *et al*., 2011; de Siqueira Zuolo *et al*., 2016; Kim *et al*., 2019; Romeiro *et al*., 2020) compared to the conventional root canal sealer. The presence of remnants can result in blockage of the apical foramen, leading to loss of apical patency in some cases (Hess *et al*., 2011). Conflicting evidence on MTA Fillapex exists in which the amount of remnants was reported to be more (Kim *et al*., 2019), similar (Kontogiannis *et al*., 2019) and less (Neelakantan *et al*., 2013) if compared to the conventional root canal sealer. Regarding the retreatment time, the removal of MTA Fillapex requires shorter (Uzunoglu *et al*., 2015), (Donnermeyer *et al*., 2018) and longer (Kim *et al*., 2019) duration compared to other root canal sealers. The shorter retreatment time in MTA Fillapex can be related to its lower bond strength to the root dentine (Neelakantan *et al*., 2013; Uzunoglu *et al*., 2015) and questionable mineralisation activity (Neelakantan *et al*., 2013). Loss of apical patency and more remnants of root canal sealer were also reported when using TotalFill BC Sealer (Kontogiannis *et al*., 2019). However, when using EndoSequence BC Sealer (Kim *et al.,* 2015) and Endoseal MTA (Kim *et al*., 2019), the remnants of root canal sealer and retreatment time were equivalent to AH Plus root canal sealer. BioRoot™ RCS showed less remnants and shorter retreatment times compared to AH Plus root canal sealer (Donnermeyer *et al*., 2018).

To date, research on the retreatability of bioceramic root canal sealers is increasing but there is still insufficient evidence to draw robust conclusion pertaining to the most effective material that can facilitate retreatment procedure.

3D obturation

The goal of obturation is to create a 3D seal of the root canal system to prevent the recurrence of bacterial infection (Schilder, 1967). 3D obturation seals not only the main canal but also the eccentricities in the root canal system (Schilder, 1967). The use of heat softens the gutta-percha and allows it to be adapted to the root canal wall with the intention to seal the exits to periodontal tissues. This technique requires careful handling of the heat source, clinical skills and more time consuming to achieve effective sealing. A modified version of this technique has been introduced such as continuous and interrupted waves of vertical compaction to achieve similar 3D obturation (Tomson *et al*., 2014) which is also technique-sensitive procedure. Without proper handling and skill, 3D obturation would not be possible.

Studies have shown that thermoplastic gutta-percha provides good adaptation to the root canal wall (Gençoğlu *et al*., 1993; Gulabivala *et al*., 1998; Venturi and Breschi, 2004; Withworth, 2005), but leakage in thermoplastic and cold lateral compaction obturation techniques have also been highlighted (Vizgirda *et a*l., 2004). Despite contradicting findings, thermoplastic gutta-percha has been shown to adapt uniformly to the root canal wall with only minor voids (Torabinejad *et al*., 1978).

Comparative studies on the ability to provide 3D obturation between bioceramic root canal sealers and other obturation techniques have not been reported because of the recent technology in endodontics. Future research works comparing various obturation techniques with bioceramic root canal sealers should be done to provide an insight into this aspect, thus can help the profession in the decision-making process with respect to the most effective materials for obturation of the root canal system.

Current practice

The obturation techniques have improved since the introduction of bioceramic root canal sealers. These developments facilitate easier methods of obturation and provide alternative to conventional obturation techniques (Topçuoğlu *et a*l., 2013).

When obturating the root canal system, the root canal sealer is used to seal the gap that is present within the root filling materials and root canal wall. To date, the monocone obturation technique is the commonly practiced because of its ease of delivery and less time-consuming, however, the quality of obturation, apical seal and bacterial penetration when using this technique are questionable (Pereira *et al*., 2012). Due to the greater volume of sealer that can be present in the complex root canal system, this technique has been considered less effective (Pereira *et al*., 2012; Robberecht *et al*., 2012). Contradictory to this, some studies have reported similar performance of this technique (Inan *et al*., 2009; Koçak and Darendeliler-Yaman, 2012; Robberecht *et al*., 2012; Obeidat and Abdallah, 2014). To overcome the limitations associated with the monocone obturation technique, the role of conventional root canal sealers have gradually been replaced by the bioceramic root canal sealers.

Studies on fracture resistance of teeth obturated with combination of gutta-percha cones and bioceramic root canal sealers have been conducted in the recent years. An increased fracture resistance was seen when using iRoot SP root canal sealer if compared to the conventional root canal sealers (Ghoneim *et al*., 2011). However, when comparing the fracture resistance of iRoot SP root canal sealer and EndoSequence BC Sealer, it was equivalent (Celikten *et al*., 2015). The increased fracture resistance in EndoSequence BC Sealer (Topçuoğlu *et al*., 2013; Hegde and Arora, 2015) or iRoot SP root canal sealer (Ghoneim *et al*., 2011) could be due to its chemical bonding through the formation of hydroxyapatite crystals during setting when the material is in contact with moisture (Ghoneim *et al*., 2011). Obturation of the root canal system using iRoot SP root canal sealer (Wang *et al*., 2018) or EndoSequence BC Sealer (Celikten *et al*., 2016), MTA Fillapex (Al-Haddad *et al*., 2015) and Smartpaste Bio® (Celikten *et al*., 2016) provided equivalent obturation quality as of AH Plus root canal sealer, as determined by the microscopic evaluation of the presence of voids and marginal gaps. Conversely, the EndoSequence BC Sealer (Al-Haddad *et al.*, 2015) and MTA Fillapex (Polineni *et al*., 2016) exhibited more marginal gaps when compared to resin-based root canal sealers. These opposite findings could be associated with the different obturation techniques used in their studies. On the other hand, iRoot SP root canal sealer (Zhang *et al*., 2009; Ersahan and Aydin, 2013) and TotalFill BC sealer (Hasnain *et al*., 2017) were equivalent to AH Plus root canal sealer in apical sealing ability, as determined by dye penetration method (Hasnain *et al*., 2017) and fluid filtration analysis (Zhang *et al*., 2009; Ersahan and Aydin, 2013).

In general, regardless of any obturation techniques and root canal sealers, the presence of voids and marginal gaps is inevitable (Nabavizadeh *et al*., 2013; Samadi *et al*., 2014; Adhikari and Jain, 2018; Jain and Adhikari, 2018; Wang *et al.*, 2018).

Conclusion

To date, robust scientific evidence on the obturation of the root canal system with bioceramic root canal sealers is limited, therefore, its use in clinical practice must be considered with great caution, taking into consideration the physicochemical properties, biocompatibility, biomineralisation as well as retreatability of each material. Since the clinical data concerning obturation with bioceramic root canal sealers is lacking, the selection of materials should be made based on the available scientific evidence, individual cases, material availability and operator's preference.

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Conflict of interest

None

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