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Review

Current Bio-based Cements and Radioactive Opacifiers in Endodontic Approaches: A Review of the Materials Used in Clinical Practice

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ABSTRACT

Objective: This study aims to evaluate the importance of endodontic root canal sealers in filling cavities and irregularities in root canals with the primary goal of minimizing or eliminating bacterial residues. Despite this crucial objective, it's noteworthy that several conventional sealers have been linked to adverse effects, such as impaired wound healing, inflammation, and bone resorption. Therefore, there is a constant search for an optimal sealer that can effectively mimic the properties of lost tissue while maintaining an acceptable level of biological, physicochemical and biocompatible properties. The present study analyzes bioceramic cement's properties in endodontics through a comprehensive review of the available literature. Also, to evaluate the beneficial properties and characteristics of the biomaterials highlighted in this work.

Methods: The present study used a systematic review approach to conduct a comprehensive literature search to find relevant publications on bioceramic cement properties in the endodontics field. Articles were retrieved using MeSH keywords and digital searches of journal websites. The selected studies were examined to extract data on sealability, bioactivity, pH, cytotoxicity, color change, radiopacity, edge adaptation, adhesive strength, antibacterial properties and biocompatibility.

Results: The results of the reviewed research show that bioceramic endodontic cement has favorable properties for the therapeutic treatment of root canals. The literature highlights the material's biocompatibility, low cytotoxicity, bioactivity, radiopacity, appropriate pH value, favorable edge adaptation, high adhesive strength, practical sealability, antibacterial properties and minimal color change.

Conclusion: Research results to date indicate that biomaterials used in endodontics have beneficial properties for root canal therapy and mimicking natural tissue regeneration. The beneficial properties of these materials, such as their biocompatibility, bioactivity, radiopacity, pH stability, edge conformability, adhesion strength, sealability and antibacterial properties, make it a promising replacement for traditional sealers. Further studies are needed to investigate the extended clinical effectiveness of the above intervention and to refine its composition to improve the outcomes associated with endodontic therapies.

Keywords: Bioceramics, Biomimetic materials, Endodontics, Radiopacifiers.

INTRODUCTION

Endodontic treatment aims to prevent and cure apical periodontitis by destroying the microbial ecosystem through chemical-surgical or chemical-mechanical preparations. After cleaning and shaping, the filling must seal the root canal system as tightly as possible. Although zinc oxide eugenol (ZOE) based, calcium hydroxide based, glass ionomer-based, resin-based, and bioceramic sealers have been used to fill root canals, problems with biocompatibility, suboptimal sealability and long-term stability have been reported [1]. Therefore, to better serve patients undergoing root canal treatment with better outcomes and better adhesion between obturation materials and the canal walls, there is an urgent need for an improved endodontic cement that effectively addresses these challenges [2]. Physical properties such as setting time, radiopacity and solubility, and chemical properties such as pH and biocompatibility are critical to selecting the filling material. Bioceramic material is often used as endodontic cement in dental restorative procedures due to its remarkable properties and compatibility with dental tissues. Bioceramic-based cements are promising because of their excellent biocompatibility, practical sealing ability that prevents microbial activity, and ability to promote tissue regeneration in dental restorative procedures. Increase the success rate by improving the sealing ability or blocking any reinfection passage, thus ensuring the longevity of the treated teeth. Bioceramic materials are mainly composed of calcium silicates and have been proven to have excellent biocompatibility with the surrounding tissue. This leads to the formation of an appetite layer during the setting process, which influences the bond between dentin and the filling material [3].

Main Points;

- Several new endodontic biomaterials have emerged in recent research studies.
- A comprehensive review of the literature has been conducted to categorize these biomaterials based on their composition and intended applications.
- The assessment aims to identify their biological and physicochemical properties, biocompatibility, cytotoxicity, bioactivity, antimicrobial effects, and ability to penetrate dentinal tubules, all of which are associated with these novel biomaterials.
- Additionally, the research includes the determination of their radioopacity, radiodensity characteristics, and the presence of radio-opacifier additives.
- It is evident that further in vitro and in vivo investigations, along with well-designed long-term clinical studies, are required to elucidate the mechanisms and validate the sustainability of these novel endodontic biomaterials in practical dental applications.

Root fillings are known to emerge coronally and come into contact with the oral flora, as numerous studies have shown. In in vitro and in vivo studies, dyes and bacteria were found to penetrate filled canals within three months and bacterial endotoxin within 21 days. Conventional root canal sealers possess inherent drawbacks, such as undergoing volumetric shrinkage upon curing and dissolution when exposed to tissue fluids. These issues can lead to the formation of voids within the sealing material, potentially facilitating the escape of microorganisms. In the context of endodontic therapy, a fundamental tenet is the complete three-dimensional obturation of the endodontic spaces, ensuring their permanent isolation from the root canal contents, thereby mitigating irritation of periapical tissues and cross-infection reactions. However, despite advancements in technology, the efficacy of bioceramic root canal sealers remains uncertain owing to limited scientific understanding and research in this area [4]. Endodontic cement often contains radiopaque means for radiographic visibility. Recent research has shown that endodontic cement radiopacifiers improve clinical outcomes and diagnostics [5, 6]. Bismuth oxide, zirconium oxide and barium sulfate increase the radiopacity of endodontic cement [6, 7]. This helps radiographs show cement placement, assessment of root canal filling, and possible complications. Endodontic cement's radiopacity helps monitor healing, assess treatment success and identify problems at follow-up visits. Clear visualization of the cementum allows assessment of its integration with surrounding structures, identification of voids or leaks, and detection of complications such as periapical pathology or root fractures. Recent literature emphasizes the importance of selecting radiopaque additives that provide sufficient radiopacity without compromising material properties or biocompatibility [8]. To optimize performance and patient safety, radiopacifier studies examine cement properties such as setting time, pH, solubility, and antimicrobial properties [9]. Recent studies have examined how radiopacifiers affect the biocompatibility of endodontic cement and tissue response; the use of bismuth oxide as a radiopacifier in endodontic materials has been widely used. Gandolfi et al. showed in vitro that the cement's biocompatibility may also be reduced or impaired. [10, 11]. Radiopacifiers that maintain biocompatibility and minimize effects on periapical tissue are under investigation[8] .

To achieve these objectives, one must consider the filling technique and the material, always considering its biological, physical, and chemical properties. The physical properties stand out: setting time, radiopacity, film thickness, solubility, flow, and dimensional stability were performed according to the American National Standard Institute/American Dental Association (ANSI/ADA) specification no. 57/2000 and ISO 6876/2001 [12].

Although these materials have good biological properties, there is a limited amount of work evaluating the physicochemical properties of bioceramic endodontic cement. Thus, it is opportune to carry out the present research to make possible and safe the use of these materials in clinical practice. The current work will discuss information related to the bioceramic cement used for endodontic cement.

Aim and Motivations of the Present Contribution

Bioceramic contains endodontic cement, which yielded many improved performances and has gained importance lately in endodontic practice due to its unique properties, as pointed out. Bioceramics'' impact on treating various pulpal or periradicular infections shows fast improvement. Researchers have emphasized that these biocompatible materials could significantly serve as valuable elements for several functions for different endodontic treatments, obtaining beneficial results and showing great promise in the treatment prognosis [13].

Hence, there is a need to address further the detailed characteristics of endodontic bioceramic sealers or cement and their radiodense contents. When the current literature is evaluated, there is a lack of a comprehensive review article about bioceramics used in endodontic practice, which comprehensively evaluates the materials in all aspects and their radio-opacifier additives. This review aimed to evaluate chemical, biological, physical, and mechanical progress, recent research outputs, and prospective endodontics applications.

MATERIALS AND METHODS

Eligibility Criteria

After discussing the research question, the aims of the study, and potential methodological limitations, the reviewers agreed on a set of inclusion and exclusion criteria. Studies analyzing the effects of different radiopaque additives on the physical properties and radiopacity of bioceramic-based materials used in endodontics were considered appropriate. The bioactivity potential of these root canal sealers was also evaluated, along with in vitro studies investigating the potential cytotoxic or inflammatory effects of radioactive additives in bioceramic-based materials and how these can be minimized. In addition, in vivo biocompatibility tests were performed. Bioceramic cement was tested for its effectiveness in endodontics. The benefits of bioceramic cement were evaluated based on a review of the existing literature on the subject. These benefits were analyzed regarding biocompatibility, cytotoxicity, bioactivity, radiopacity, pH, marginal conformability, bond strength, sealability, antibacterial properties and possible color change. This research aimed to investigate the use of bioceramic cement for root canal therapy and determine its effectiveness and potential for advancing endodontic practices.

Search Strategy

This study thoroughly examines bioceramics' role in endodontics by conducting a comprehensive literature search. To gather relevant articles, an electronic survey was conducted using databases like PubMed, Scopus, Web of Science, and Google Scholar, and MeSH keywords like" dental materials+endodontics"," bioceramic+root canal sealer"," bioceramics+endodontic"," cements+endodontic"," hydraulic cements+endodontic", and"radiopacity" or"radioopacifier". Only peer-reviewed articles written in English were included, and a preliminary screening was conducted to ensure that met the inclusion criteria. After checking all studies for relevance, a total of 75 articles were selected for this study. Based on the PRISMA guidelines, Figure 1 shows the selection criteria used for our study. As part of our analysis, we assessed 51 articles for their research quality. Of the selected articles, 88% were original research papers. As of May 23, 2023, the study's findings revealed that a significant amount of research was conducted on bioceramic root canal sealers, as indicated in Figure 2 (a-c).

RESULT AND DISCUSSION

Bioceramic Materials Used in Endodontics

Bioceramics exhibit excellent bioactivity and biocompatibility, inducing a regenerative response in the human body and promoting hydroxyapatite formation. It can be osteoinductive and absorb osteoinductive substances, making it ideal for root cement in endodontics [14]. The material includes dicalcium and tricalcium silicates, calcium phosphates, zirconium oxide, and calcium hydroxide [15, 16]. Bioceramic cement is popular due to its high pH, biocompatibility, non-resorption, low cytotoxicity, increased root resistance, and stability. First-generation bioceramics, such as alumina and zirconia, had excellent mechanical properties. The second generation, such as calcium phosphate-based hydroxyapatite and bioactive glass (BG) cement, adhere to the living bone without causing inflammation or toxicity [17]. BG cement has healthcare and modern biomaterial-driven medicine. In endodontic practice, biomaterials are used for various treatment procedures, such as pulp capping for vital pulp treatment, root canal filling as an intracanal sealer, and extraarticular repair material [18], Figure 3 shows The use of biomaterials in endodontic practice. The common types of bioceramic materials used in endodontics include:

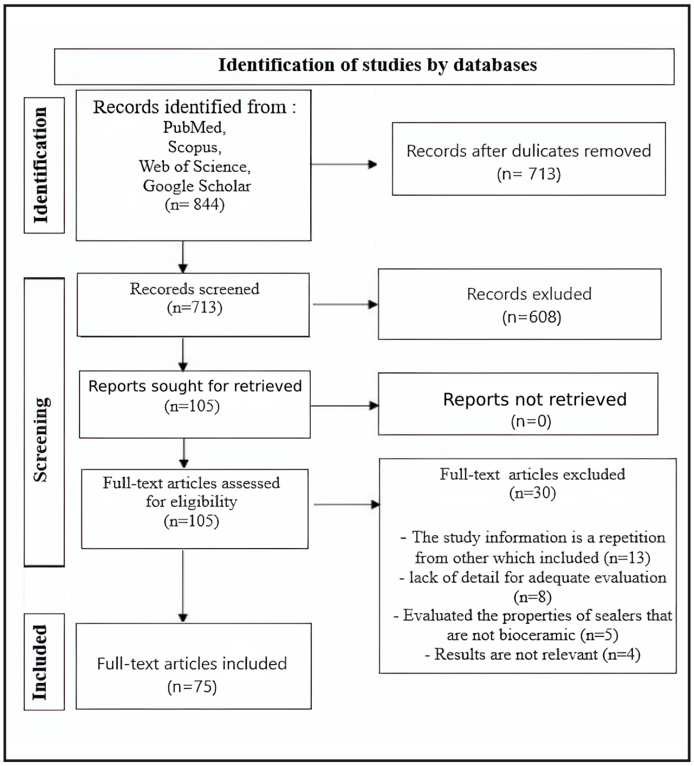

Figure 1. A PRISMA flowchart illustrating the collection and curation of data from the web.

Calcium Silicate Containing Cements

Mineral trioxide aggregate (MTA) cement is a bioactive cement introduced in the 1990s as a root-end filling material for endodontic treatment. Since then, its use has expanded to various clinical applications such as pulp capping, apexification, perforation, and furcation repair. MTA is composed of finely ground Portland cement, bismuth oxide, and other minerals and has a unique chemical composition that provides excellent sealing ability, biocompatibility, and the ability to induce complex tissue formation [19].

MTA comprises tricalcium aluminate, dicalcium silicate, calcium oxide, silicon dioxide, tricalcium silicate (66.1%), aluminium oxide, and Bi2O3 as a radiopacifier [20]. MTA has some of the ideal properties of repair material. However, Portland cement and MTA may contain heavy metals in their composition, with arsenic levels higher than the safe limit specified by ISO 9917-1 of 2007. In addition, there is evidence that Bi2O3 interferes with the hydration mechanism[21]. They were promoting failures in the microstructure of Portland cement. Consequently, there is an increase in porosity, resulting in a decrease in the strength of the material [22].

The replacement of MTA by tricalcium silicate has been evaluated, resulting in materials with promising physicochemical properties [20]. Replacing Portland cement with tricalcium silicate allows better control over impurities and heavy metal inclusions found in Portland cement.

Modifications in MTA composition gave rise to MTA Plus (MTAP) (Avalon Biomed Inc., Bradenton, FL, USA), a commercially available material based on tricalcium silicate in powder-liquid or gel form. According to the manufacturer, it is indicated for vital pulp therapies (pulp capping and pulpotomy) and endodontic procedures (repair of perforations and resorptions, apexification, apexogenesis, root canal, and retro filling). Its composition comprises tricalcium silicate, dicalcium silicate, and Bi2O3 [23]. As a material used in pulpotomy teeth with incomplete root formation, MTAP induces the release of calcium hydroxide as a by-product and the formation of calcium phosphate when in contact with tissue fluid; however, it causes staining in contact with sodium hypochlorite due to Bi2O3. Biodentine cement is a calcium silicate-based material that has gained attention in dentistry due to its beneficial properties and clinical applications. It is biocompatible, meaning it is well-tolerated by the surrounding tissues. It also has bioactive properties, promoting the formation of hydroxyapatite and facilitating the remineralization of dentin [24]. Biodentine cement offers several advantages compared to other materials. It has similar mechanical properties to natural dentin, making it a suitable substitute[24]. It also has a simplified handling process, with a powder and liquid component that can be easily mixed. Biodentine can be used in various clinical scenarios, including direct and indirect pulp capping, apexification, and dentin substitutes for restorations [25]. Table 1 shows the common calcium silicate-containing cement.

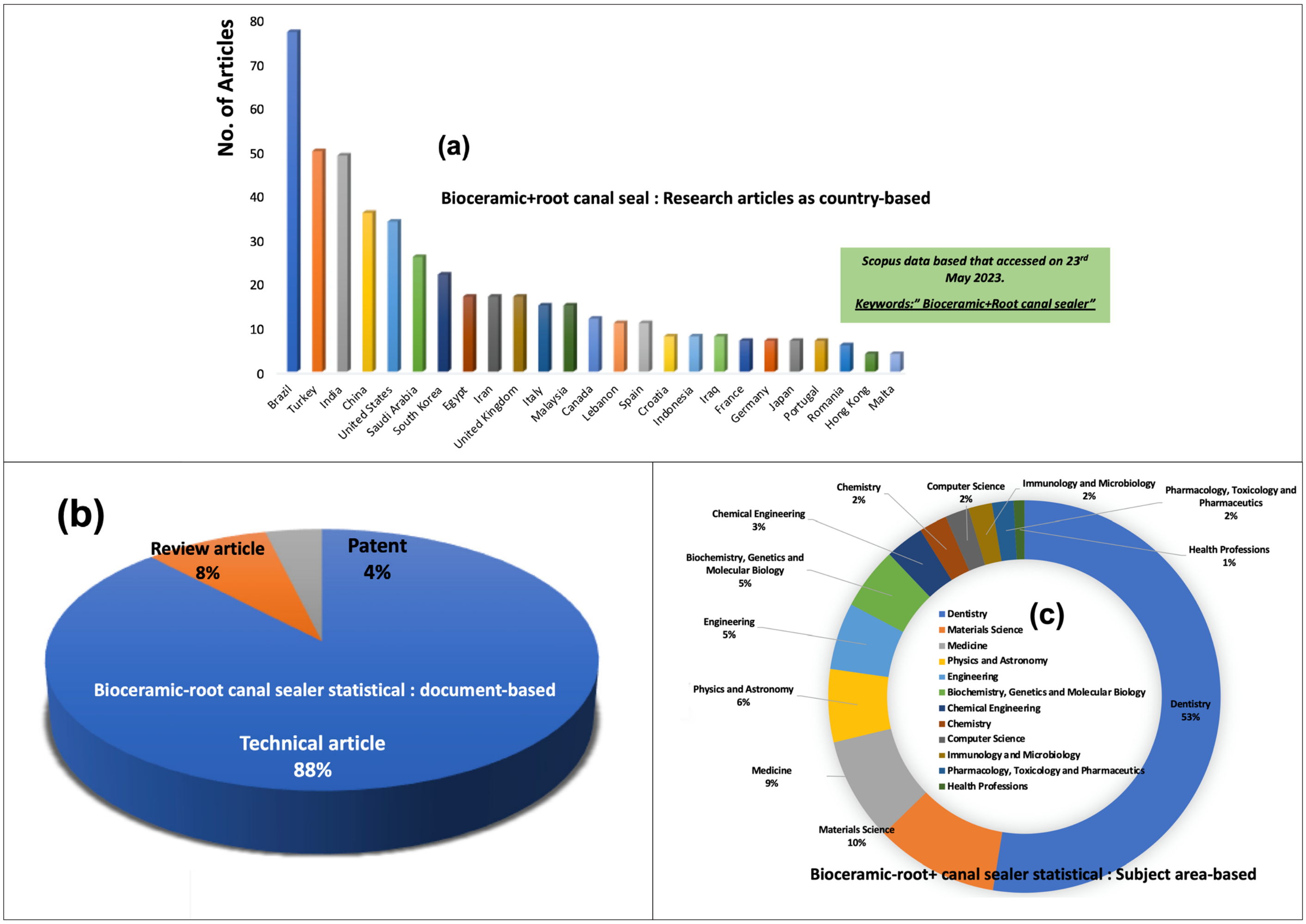

Figure 2. Bioceramic, root canal sealer statistical analysis on (**a**) research article: country-based, (**b**) document –based and (**c**) subject area-based. After screening all studies for relevance, a total of 75 articles were selected for this study. Of the selected articles, 88% were original research papers. As of May 23, 2023, the findings of the study revealed that there had been a significant amount of research conducted on bioceramic root canal sealer, as indicated in Figure 2 (**a-c**).

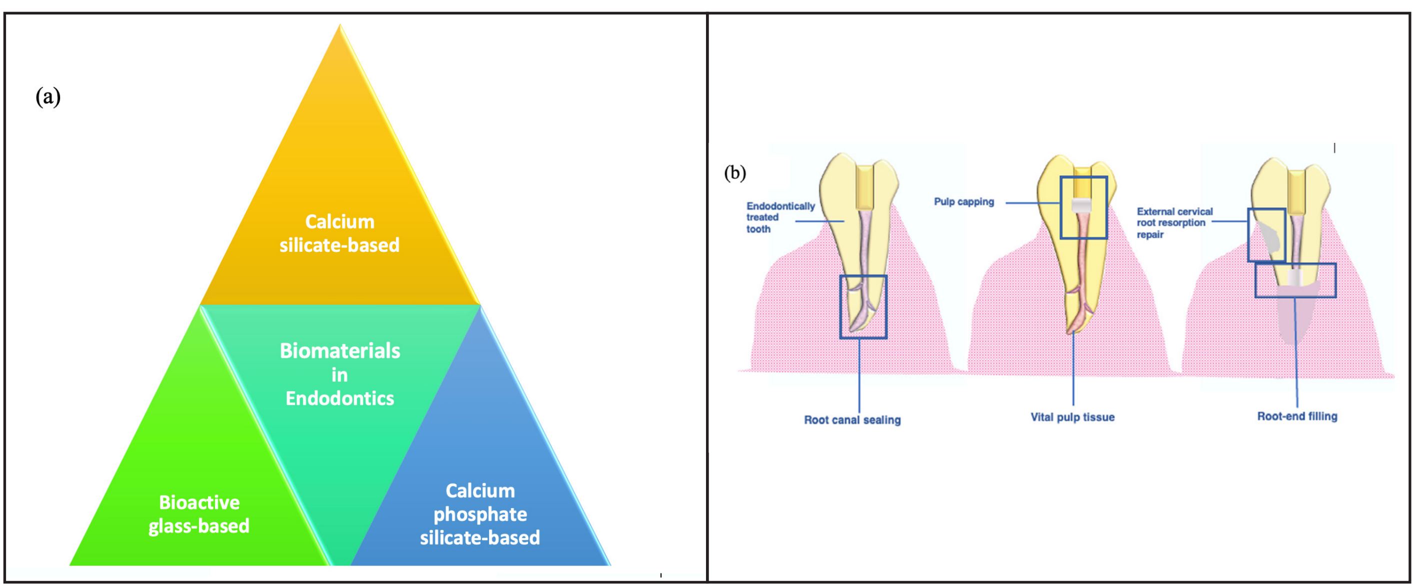

Figure 3. The use of biomaterials in endodontic practice

Table 1. Common types calcium silicate containing used in endodontics.

Product	Company	Composition	Radioopacifier additive	Product format	Form	Conditions of use
ProRoot MTA	DENTSPLY Tulsa Dental Specialties	Tricalcium silicate , dicalcium silicate , calcium dialuminate , and calcium sulfate dehydrated .	Bismuth oxide	Powder + liquid (water)	Cement	Pulp capping, pulpotomy, apexification, perforation repair, root-end filling
MTA Angelus	Angelus Dental Solutions	Tricalcium silicate, dicalcium silicate, tricalcium aluminate, tetracalcium aluminoferrite, calcium sulfate and bismuth oxide	Bismuth oxide	Powder + liquid (water)	Cement	Pulp capping, pulpotomy, apexification, perforation repair, root-end filling
MTA Repair HP	Angelus Dental Solutions	MTA Repair HH.P.is based on the formulation of conventional MTA but contains calcium tungstate as radiopacifier and a mixing liquid with a plasticizer agent	Calcium tungstate	Powder + liquid (water with polymer plasticizer)	Cement	Pulp capping, pulpotomy, apexification, perforation repair, root-end filling
MTA Plus	Prevest DenPro Limited	Similar in composition to ProRoot MTA (Dentsply) but is ground finer.	Bismuth oxide	Powder + liquid (water with proprietary polymer)	Root canal sealer	Pulp capping. Cavity lining. Pulpotomies.
MTA Flow	Ultradent Products, Inc.	Extremely fine, inorganic powder of tricalcium and dicalcium silicate	Bismuth oxide	Powder + liquid (water-based gel)	Cement	Pulpotomies, pulp capping, rootend filling, apexification, perforation repair, and root resorption
MTA Vitalcem	Brasseler USA	Has a composition similar to that of conventional MTA	Zirconium dioxide	Powder + liquid (calcium chloride and water)	Cement	Vital pulp therapy
Biodentine	Septodont	Tricalcium silicate, dicalcium silicate, calcium carbonate and oxide filler, iron oxide shade, and water	Zirconium oxide.	Powder + liquid (calcium chloride , hydro-soluble polymer)	Cement	Pulp capping. Indirect pulp capping. Revitalization. Root canal obturation. Root canal retreatment. Simple tooth extraction. Vital pulp therapy.
EndoSequence Root Repair Material	Brasseler USA	Dicalcium silicate , tricalcium silicate , calcium hydroxide , fillers	Zirconium oxide.	Single componet(paste or putty)	Cement	Repair of root canals and root perforations
TotalFill BC Sealer	FKG Dentaire	Dicalcium silicate , tricalcium silicate , calcium hydroxide , fillers	Zirconium oxide.	Single componet(ready to use)	Root canal sealer	Permanent obturation of the root canal
Ceraseal	Meta Biomed	tricalcium silicates, dicalcium silicates, calcium aluminates,	Zirconium oxide.	Powder + liquid (water)	Root canal sealer	permanent root canal sealing and for the permanent root canal filling
Dia root bio sealer	DIADENT GROUP INTERNATIONAL	Calcium Silicates, calcium aluminates, Calcium Oxide, and iron oxide	Zirconium Oxide	ready to use	Root canal sealer	Permanent root canal obturation

Calcium Phosphate-Silicate Containing Cements

Developing new biomaterials for orthopedics and dentistry based on calcium phosphate cement is relevant since they have a chemical composition similar to the mineral phase of bones and teeth and a series of advantages derived from their process. Hydraulic cement can be defined as mixtures of inorganic materials that set and develop mechanical strength by chemically reacting with water and forming hydrates [26].

The cement's consolidation occurs in two stages: setting and hardening. When mixed with water, a plastic paste is formed that loses elasticity with time and increases its mechanical strength so that if molded or remixed with water, the plasticity is restored or re-established. In the second stage, consolidation occurs, usually accompanied by the loss of water permeability, where the maximum resistance value is reached after several hours, days, or months [27].

The setting and hardening of cement involve a chemical reaction (dissolution, precipitation, or hydrolysis). The setting is a weak colloidal stage in crystal lattice development, while hardening leads to an irreversible crystal structure. This theory is based on LeChatelier's principle, which explains hardening through crystallization. Introducing the concept of an early colloidal stage explains cement measurement and setting phenomena [28].

The time during which the cement paste behaves eminently in a thixotropic form, called setting time, is strictly related to the working time, to the time available to prepare and place the cement definitively. The method used to measure this setting time, considering the time from which the needle used does not completely penetrate the cement mass, is performed by a device called Vicat [29]. Among the range of advanced endodontic sealers available, BioAggregate, iRoot SP, and Cerafill RCS stand out with distinctive qualities. BioAggregate impresses with its rapid setting time and potent antimicrobial effects, making it ideal for vital pulp therapy[30]. iRoot SP, on the other hand, focuses on biomineralization and sealing ability, along with efficient flow in intricate canals, and BioRoot RCS emphasizes silicone-based stability, dentin adhesion, and dimensional reliability [31]. The selection among these sealers hinges on the specific clinical context, necessitating carefully considering each product's unique strengths and suitability for the intended endodontic procedure.

There are many different types of Calcium Phosphate commercially available, including Cem-Ostetic (Calcium phosphate powder with Sterile water), MBCP® putty (β-TCP with Hydrogel), α-BSM (amorphous calcium phosphate, dicalcium phosphate dehydrate with Unbuffered aqueous saline solution), KyphOs™ FS (TCP, Mg3 (PO4)2, MgHPO4, SrCO3 with H2O, (NH4)2HPO4)), JectOS® (TCP and dicalcium phosphate dehydrate) and Quick Set Mimix,(Calcium phosphate powders, Na3C6H5O7•2H2O with Citric acid aqueous solution, etc. [32]. Due to their superior performance to brushite CPCs, it can be seen that the majority are apatite CPCs. Apatite CPCs are relatively non-degradable, which has limited their ability to be used more frequently in clinical settings. Therefore, to increase their clinical use, it is crucial to improve apatite CPC degradation. The common type of calcium phosphate-silicate-containing cement is detailed in Table 2.

Table 2. Common types of calcium phosphate silicate-containing cement used in endodontics.

Product	Company	Composition	Radioopacifier additive	Product format	Form	Conditions of use
BioAggregate	Innovative BioCeramix	Tricalcium silicate, tantalum oxide, calcium phosphate, silicon dioxide	Tantalum oxide	Powder + liquid (water)	Cement	Root repair, pulp capping, or pulpotomy procedures.
iRoot S.P.	Innovative BioCeramix	Tricalcium silicate, zirconium oxide, dicalcium silicate, calcium sulfate, calcium phosphate monobasic, and filler agent	Zirconium oxide.	Single componet(paste or putty)	Root canal sealer	Obturation of the root canal system
Cerafill rcs	PREVEST DENPRO LIMITED	Calcium Silicates, Calcium Phosphates, Bioactive Glasses, Calcium Sulphate, Calcium Oxide	Zirconium Oxide	ready to use	Root canal sealer	Permanent root canal obturation

The Bioactive Glass containing cement

The BG was developed in the 1960s, and the glass compositions of Na_2O–CaO–SiO_2 were explored from 1969 to 1971 to find a material implanted in the human body without forming scar tissue around the device. The 45S5 formulation, 45% SiO_2, 24.5% Na_2O, 24.5% CaO, and 6% P_2O_5 (wt %), which has a high Na_2O and CaO content and relatively high CaO/P2O5 ratio that makes the surface of the material highly reactive in a physiological environment. Due to its proximity to the ternary eutectic, this composition was chosen because of its high concentration of calcium oxide[33]. BGs are not allowed to be referred to by the trademarked term Bioglass. Biological Glass® is distinguished by silica (SiO2), a network-forming oxide in the form of the SiO4 tetrahedron, as the fundamental unit of the glass network. An oxygen link may be bridged between teams by –Si–O–Si– bridging oxygen bonds, allowing for the construction of a 3D network. As network moderators, sodium and calcium break up the network and form non-bridging oxygen bonds [34].

Glass type Na2O-CaO-SiO2-P2O5 in specific proportions [35], with silica (SiO2) component 50% mol%. BG has been used in the field of orthopedics for decades. After implantation of BG in a defect near the bone, several reactions on the material surface release critical concentrations of soluble P, Ca, Si, and Na ions, which induce favourable extracellular and intracellular responses, leading to the rapid formation of bone [35].

Commercially available root canal sealers that contain BG are available on the market. Some bioseal materials include GuttaFlow Bioseal (GFB), which consists of gutta-percha and polydimethylsiloxane, platinum catalyzer, zirconium dioxide, and BG. Despite its low porosity, solubility, alkalization capacity, dentin penetration, and cytocompatibility, GFB is cytocompatible [36]. The limited published evidence is currently available on the mechanism of the mentioned sealer hardening or its ability to seal and be removed for re-entry [17]. Nishika Canal Sealer BG (CS-BG) is the second product; there is compelling evidence about its removability, biocompatibility, physicochemical properties, and sealing ability. Bone and dentin-pulp complex regeneration were the original goals of the created CS-BG biomaterials .CS-BG's Paste A includes fatty acids, silica dioxide, and bismuth subcarbonate, while Paste B has magnesium oxide, dioxide, and calcium silicate glass (a type of BG). These paste are dispensed in a 1:1 ratio through a double syringe and can be easily mixed. A plastic spatula is recommended instead of a stainless-steel one due to the paste's corrosive nature. To prevent the hardening of CS-BG paste due to exposure to heat or moisture, store the syringes in a resealable aluminium foil bag and then keep the bag in a cool, non-freezing storage location, with temperatures ranging between 1-10°C [17]. Table 3 lists common types BG BG-containing cement used in endodontics

Table 3. Lists common bioactive glass containing cement used in endodontics.

Product	Company	Composition	Radioopacifier additive	Product format	Form	Conditions of use
GuttaFlow Bioseal (GFB)	Coltène/Whaledent AG, Altstätten, Switzerland	Gutta-percha, polydimethylsiloxane, platinum catalyzer and BB.G.	Zirconium dioxide	Ready to use	Root canal sealer	Filling material, It acts as a sealer between the core material and root canal walls.
Nishika Canal Sealer BB.G.(CS-BG)	Nishika Canal Sealer BB.G.(CS-BG)	Two-phased paste; Paste A consists of fatty acids, , and silica dioxide, whereas Paste B consists of magnesium oxide, calcium silicate glass (a type of BB.G., and silica dioxide	Bismuth subcarbonate	Ready to use	Root canal sealer	Root canal sealer during endodontic treatment, not as a general filling material.

Hybrid Cement Containing Bioceramic Material

Hybrid endodontic cement incorporating bioceramic materials has gained significant attention recently due to its enhanced properties and clinical benefits. These cements combine traditional endodontic cements' advantages with bioceramics' unique characteristics, resulting in improved sealing ability, biocompatibility, and tissue regeneration potential [37].

One such example is the combination of bioceramic particles with resin-based materials. This hybrid approach combines the adhesive properties of resins with the bioactivity and antimicrobial properties of bioceramics. The resulting cement exhibits strong dentin bonding, reduced microleakage, and the ability to stimulate mineral deposition for tissue healing[38, 39].

Incorporating bioceramics into hybrid cement contributes to their radiopacity, allowing for better post-operative assessment and follow-up. Furthermore, the alkaline pH of bioceramics in this cement can help neutralize acidity within the root canal system and promote an environment unfavourable for bacterial growth [40].

Each sealer offers unique benefits and characteristics, catering to diverse clinical scenarios and contributing to the ever-evolving landscape of endodontic treatment.

Characterization of Sealers and Cement Used for Endodontic

Pulp capping

The material used to cover the pulp significantly impacts the success of vital pulp therapies. A pulp capping material must be both biocompatible and antibacterial to be effective. This remedy is designed to help differentiate oral pulp cells and repair dentin [41]. Pro-Root MTA (Dentsply-Sirona, New York, USA) was the first hydraulic calcium silicate cement, followed by several others [42]. The development in the marketed materials is due to the biocompatibility and long-term survival of MTA and the demand for materials with better handling, less risk of discolouration, better sealing and lower prices [43]. Resin-based calcium silicate cements are among the latest developments for pulp capping. These materials can reduce staining and adhere to the tooth structure, improving sealers performance. Adding resins can achieve better binding to resin composites and resin-modified glass ionomers on top, minimizing treatment time and reducing leakage and early loss filling. The main disadvantage of this cement is the lack of biocompatibility of the monomers with essential pulp tissue, which can prevent the formation of a complete rigid tissue barrier in the exposed area [41].

Intracanal

After biomechanical preparation and disinfection, gutta-percha intracanal sealers are used for permanent root canal filling. Epoxy resin-based sealers are the"gold standard" due to their excellent sealing, low solubility, short setting time, and cost [44]. Bioceramics' bioactive properties can template a tissue-material bond, unlike epoxy resin-based sealers. Compared to other endodontic materials, they are more biocompatible and less cytotoxic [45].

This material forms dentin bridges, is biocompatible, has an alkaline pH, and does not promote inflammation, making it promising for root perforations, retrograde fillings, and pulpal exposure treatment. In 1998, the FDA approved the MTA. Since 1993, MTA has been used in surgical and non-surgical dental applications. MTA Fillapex seals root canals with salicylate resin and MTA. Its thin film and high flow rate reach the lateral and accessory canals. Antibacterial and biocompatible MTA and salicylate resin comprise 13% of the product. After 2 hours of setup, the working time is 23 minutes.[46]

DiaRoot BioAggregate is a root canal repair material composed of ceramic nano-particles. DiaRoot Bioaggregate is non-toxic, tooth-coloured, easy to apply, expands by 20% during curing, is highly hydrophilic, and chemically bonds to dentin. It is a biocompatible pure white powder mixed with BioAggregate to form a paste. DiaRoot Bio Sealer is a pre-mixed bioceramic calcium silicate-based MTA sealer used with DiaRoot BioAggregate. It was used for Root perforations, direct capping, apexification, internal root resorptions, and retrograde root canal filling .[47]

AH-Plus Bioceramic sealer reacts with collagen's exposed amino groups to form covalent bonds and can replace dentine surface treatment or dentine glue. Dual-cure resin-based sealers bind dentine better than AH-Plus. Later, hydrophilic methacrylate resin sealers could moisten canal walls and enter dentinal tubules. AH-Plus was the least soluble, radiopacity, and setting time sealer. AH-Plus BC contains zirconium oxide, iron oxide, and calcium tungstate. Zirconium and iron oxide in AH-Plus BC made it more radiopaque than barium sulfate sealers. Since epoxy amines polymerize slowly, AH-Plus takes time to set [48].

Extraradicular

Dentinal resorption, according to Costa et al.[49], is the loss of hard dental tissue (cementum or dentin) due to odontoclast action, whether physiological (first tooth exfoliation) or pathological. The resorption of alveolar bone involves clastic cells. This can be caused by physiological, pathological, or other factors. Non-mineralized tissues like pre-dentin, the odontoblastic layer and pre-cementum on both sides of the tooth root protect the tooth root.

Dentin apical inflammation and oscillating forces were essential factors in the pathogenesis of dental caries, according to Lee et al. [50]. The most common reason was tooth movement caused by orthodontic treatment. Surface resorption is a sign of periodontal ligament or root surface damage being repaired by healthy tissue nearby. It is self-limiting because the ligament can regenerate new fibers [51]. The main cause is decayed and infected dental pulp. Bacteria may produce acids and proteases that destroy the bone matrix components, or they may stimulate the production of osteolytic factor, which promotes osteoclastic activity, as two potential mechanisms for bacterial-induced resorption. Endotoxin (lipopolysaccharides) has been linked to tooth resorption, with osteolytic factor induction serving as the prevailing mechanism. These substances represent the gram-negative bacteria's outer surface [52].

Internal resorption is treated with calcium hydroxide paste injected into the canal and resorption lacuna. To remove necrotic tissue from the lacuna, calcium hydroxide and sodium hypochlorite are used sequentially to induce necrotization. The preferred treatments for lateral resorption are pulp removal, root canal debridement, and calcium hydroxide application. After medication, warm gutta-percha can be used to compact the defect [53, 54].

MTA Repair HP (Angelus Industrial de Produtos Odotontológicos S/A, Londrna, PR, Brazil) has developed tricalcium silicate-based products. MTA Repair HP incorporates calcium tungstate to replace the bismuth oxide radiopacifier. Furthermore, MTA Repair HP has more flexibility than its predecessor, white MTA-Angelus, which improves handling and insertion into the tooth. These materials are recommended for treating dental pulps (pulp capping, cavity lining, and pulpotomies) and root canals (perforation repair, root resorption, and apexification). However, it should be noted that the cytotoxicity of the material employed during acute pulp treatment, perforation repair, and retrograde filling may impact the survival of dental or periradicular cells, resulting in cell death through apoptosis or necrosis. As a result, it is critical to avoid using toxic dental materials on pulpal and periodontal cells [55].

External cervical resorption (ECR), the loss of dental hard tissue due to odontoclast activity, includes a dynamic process that affects dental, periodontal, and pulpal tissues in the following stages. ECR has recently received significant attention due to enhanced micro-CT, histological, and radiographic CBCT detection tools. However, it is noted that further research is required to determine the causes and consequences of several potential contributing elements. The most impacted teeth are the maxillary central incisor, maxillary canine, maxillary lateral incisor, mandibular first molar, and maxillary first molar. The analogous processes in the ECR process are commencement, progression, and resorption, followed by reparative phases. Resorption, healing, or remodeling may occur simultaneously in different regions of the diseased tooth. Improved CBCT analysis accuracy leads to more accurate detection and assessment of ECR and the decision of the optimum treatment method [14].

The rationale for non-surgical therapy of perforation is to avoid periradicular irritation. This may be performed by immediately sealing the perforation with a non-irritating material that will provide a sufficient seal to prevent microbial penetration. Even if a non-toxic and biocompatible material is utilized to repair a furcal perforation, the significant lesion may cause lasting damage to the periodontal attachment mechanism at the furcation site [56]. The prognosis is dismal in the event of a late and faulty repair. To keep such teeth, adequate and early treatment of the concerned teeth is required. In large perforations, the total closure of the hole with a sealing substance is problematic because it constantly permits irritants to access the furcation region—perforations at the gingival sulcus cause chronic inflammation and sulcular epithelial down growth into the defect. Coronally situated perforations, particularly furcal perforations, are more severe than those in the middle and apical thirds of a canal [56]. Bioceramics, such as mineral trioxide aggregate (MTA) and Biodentine, have been used to treat ECR. Nonsurgical repair using bioceramic putty is an effective treatment option for ECR. MTA has been used as a filling material in ECR cases, and its use successfully manages ECR with a stable outcome. The use of MTA in ECR cases involves filling the resorptive defect with MTA. In one case report, fibre post placement using flowable composite resin and MTA was used to fill the resorptive defect. The use of MTA provides better conditions to access the resorption process. Effective management and appropriate treatment can only be carried out if the true nature and exact location of the ECR lesion are known. MTA has been widely used in pulp capping, apexogenesis, pulpotomy, and perforation repairs. MTA is the best material for repairing gaps. Strip, lateral, and furcation holes have all been effectively repaired by MTA, as shown by many trials with long-term follow-up. MTA's various benefits include its excellent sealing feature, biocompatibility, bacteriostatic or bactericidal qualities, radiopacity, and the ability to set in the presence of blood or moisture. Cementum formation is facilitated by cementoblasts, which MTA initiates. MTA's disadvantages include a longer setting time, challenging handling, and the possibility of discolouration[56]. Table 1 shows the characterization of different types of bioceramic sealer and cement used in endodontic practical.

Biological and Physicochemical Properties of Sealers/ Cement

Root canal filling is the endodontic treatment aiming to fill the newly decontaminated root canal system to prevent bacterial microleakage from the oral environment and apical and periapical tissues. This filling is considered one of the keys to the success of endodontic therapy.

One of the purposes of obturation is to prevent microorganisms from proliferating within the root canal system, making them impermeable and preventing the passage of microorganisms from the oral cavity or apical tissues to the canals. In addition, due to its flow, the cement reaches regions of the isthmus, secondary channels, accessories, and variable extensions in the dentinal tubules, reducing marginal microleakage and repairing periradicular tissues and conditions for the maintenance of periapical health [57].

An ideal cement's physical, chemical, and biological properties are good sealing, biocompatibility, antimicrobial activity, dimensional stability, insoluble in the oral environment and tissue fluids, adequate flow and low viscosity, and filling irregularities and spaces between the cones. Bonding dentinal walls and cement, ease of manipulation and insertion in the canal, radiopacity, not changing the color of the dental crown, adequate setting time, adaptation and adhesion to the root canal walls, being reabsorbed in the periapex when extravasated, stimulating or allow deposition of repair tissue and ease of removal when necessary[57].

Dentinal Tubule Penetration

The long-term success prognosis of the root canal treatment includes some essential steps, such as dimensional obturation of the shaped and disinfected root canal system; the sealers should adhere to the material and dentinal walls to avoid voids at the dentine-sealer interface [58].

The penetrability of sealers used in endodontic practice into dentinal tubules and anatomically complex areas directly relates to the flow property. The voids and leakage after root canal treatment may disturb the healing process. A moderate flow is desirable to access areas that need to be filled and not leak into the periapical region [59]. Regarding the sealer penetration, outcomes are inconsistent with the pressure on the obturation material during application to thrust the sealer into the tubules; however, several studies could not find a relationship between the type of obturation and penetration depth [60, 61].

There is no reliable information that sealers were labelled with any other fluorescent dye, except for the studies mixed with rhodamine B. one study utilized calcium as a marker [62], which was lower than those expected from previous studies. However, this technique is also not yet validated, and no other method is available except for confocal scanning[62]. Due to its resorption resistance and dimensional stability, AH Plus (DENTSPLY DeTrey, Konstanz, Germany) has been the gold standard material for hydrophobic epoxy resin-based sealers. However, it has drawbacks, including the possibility of mutagenicity, cytotoxicity, and an inflammatory reaction[63].

Furthermore, its hydrophobicity prevents the hydrophilic channel from being filled. Retained dental moisture, in particular, may cause errors in AH-Plus adherence to the canal walls; besides, a renewed sealer-based calcium silicate, a recently introduced sealer, Total Fill BC Sealer HiFlow (TFHF) (FKG Dentaire, St. Maur de Fossés, Switzerland) on the market that recommended usage for warm obturation techniques [64, 65].

Evaluating the filling quality with tubule penetration of bioceramic endodontic sealers is limited and leads to inconsistent results. Akçay et al.[66] compared the dentinal tubule penetration of various root canal sealers after the application of different final irrigation techniques, namely, conventional needle irrigation (CI), Er:YAG laser with photon-induced-photoacoustic streaming activation (PIPS), and passive ultrasonic activation (PUI). The sealer types investigated were AH Plus, iRoot SP, MTA Fillapex, and GuttaFlow Bioseal. A total of 156 human mandibular premolars were examined, and the samples were sectioned at 2, 5, and 8 mm from the apex to assess the dentinal tubule penetration using a laser scanning confocal microscope. The results showed that iRoot SP exhibited a significantly higher penetration area than the other groups, whereas there were no significant differences between AH Plus, MTA Fillapex, and GF Bioseal. PIPS and PUI had significantly higher penetration than CI. Statistically significant differences were also determined at each root canal third, with the coronal third showing the highest penetration and the apical third the lowest. The study concluded that the selection of root canal sealer, final irrigation procedure, and root canal third significantly affected the dentinal tubule penetration area, and the use of iRoot with PIPS tip or PUI seems advantageous in dentinal tubule penetration. Fernández et al. [67] evaluated the ability of a calcium silicate-based sealer (iRoot SP) and an epoxy resin-based sealer (Topseal) using two gutta-percha filling techniques to fill artificial lateral canals (ALCs) in extracted human teeth and penetration of sealer and/or gutta-percha into the ALCs. The results indicated that the calcium silicate-based sealer with continuous wave of condensation was more effective in artificially filling lateral canals than the single-point technique. The epoxy resin-based sealer with both filling techniques was effective in artificially filling lateral canals. The apical third was associated with the lowest acceptable filling, followed by the middle and coronal thirds.

Başoğlu et al. [68] compared the penetration characteristics of two commonly used root canal sealers, Ah Plus and MTA Fillapex, following irrigation activation with different techniques, namely sonic, passive ultrasonic, SWEEPS, and XP-Endo Finisher, using confocal microscopy.160 mandibular premolar teeth were randomly allocated to four groups and eight subgroups. Confocal microscopy was used to examine three sections at different levels, and statistical analysis found significant differences in material, device, and region. The results suggested that SWEEPS as an irrigation activation technique holds promise in enhancing dentin tubule penetration by root canal sealer.

Antimicrobial Properties

Antimicrobial activity can increase the success rate of treatments in the endodontic practice, as they eliminate residual infections, whether bacteria arising from the treatment of the dental element or infiltrated later. However, evidence was insufficient on bioceramic-based sealers' long-term sealability or prognosis [69]; if a sealer used in a root canal system has antimicrobial activity, it can reduce a load of residual microorganisms [70] and may provide support in preventing secondary infections [71] .

It was reported that the freshly mixed root canal sealers are effective against some microorganisms; thus, the effectiveness between 2 and 7 days later was not reported; within this research, a significant number have focused on comparing the various materials in vitro[72]. The literature demonstrated that Enterococcus faecalis (*E. faecalis*) is one of the microorganisms in necrotic pulp, especially in teeth with secondary root canal infection [73]. Other microorganisms, including *M. luteus, E. coli, S. aureus, P. aeruginosa, C. albicans*, and *S. mutans*, have also been used to evaluate the antibacterial effects of endodontic sealers [3].

Analyzing the antibacterial impact is relevant to clinical practice. Commonly used models to evaluate antibacterial activity are the direct contact test (DCT), agar diffusion test (ADT), and modified direct contact test (MDCT)[74]. Hasna et al. [75] evaluated the antibiofilm action, biocompatibility, morphological structure, chemical composition, and radiopacity of five mineral oxides (5MO), mineral trioxide aggregate repair high plasticity (MTA Repair HP), and mineral trioxide aggregate (MTA) cements. The findings indicate that 5MO, MTA Repair HP, and MTA were effective against five anaerobic microorganisms and demonstrated biocompatibility with mouse macrophage and osteoblast cultures. It also possessed adequate radiopacity for clinical usage. Jerez-Olate et al. [76] evaluated the antibacterial efficiency of calcium silicate repair cement and sealers against a dual-species planktonic aerobic model with varying ageings and the capacity to suppress the establishment of a 21-day-old multispecies anaerobic biofilm. The bactericidal effectiveness of MTA Angelus, Pro-Root MTA, Biodentine, TotalFill BC, and BioRoot RCS against a dual-species aerobic planktonic model was investigated using the MDCT. SEM and CLSM were used to investigate the capacity to suppress biofilm development. Biodentine and BioRoot RCS exhibited a stronger antibacterial effect, and Biodentine maintained its antibacterial action in vitro. Antibiofilm action was more significant in MTA Pro-Root and Biodentine.

Setting Times and Behavior in the Biological Environment

Setting times of endodontic cement" refers to the time it takes for the cement to harden and become stable. The setting times of endodontic cement vary depending on the type of cement and the clinical application. Generally, the optimal start time is between 4-8 minutes, and the final time is 10-15 minutes. Quick hardening is convenient, but the surgeon needs enough time to mold and implant it in the surgical site [77]. The particle size in the initial powder is also essential for the cement's setting and final properties. Smaller particles lead to faster dissolution and more excellent hardening rates due to the precipitation of a new phase through a precipitation dissolution mechanism [78].

Queiroz et al.[79] evaluated tricalcium silicate-based experimental materials, associated with different radiopacifiers such as zirconium oxide (ZrO2), calcium tungstate (CaWO4), or niobium oxide (Nb2O5), in comparison with MTA Repair HP (Angelus). The results showed that all the materials presented alkaline pH, antibacterial activity, low solubility, and no cytotoxic effects. The highest alkaline phosphatase activity occurred in 14 days, especially to TCS, TCS + ZrO2, and TCS + CaWO4. TCS + ZrO2, TCS + Nb2O5, and MTAHP had higher mineralized nodule formation than those of the negative control. After 7 days, there was no difference in mRNA expression for ALP, when compared to NC. However, after 14 days, there was no overexpressed ALP mRNA, especially TCS + Nb2O5, in relation to the CN. All the materials presented antimicrobial action. Lucas et al. [80], evaluated the physicochemical properties and dentin bond strength of the tricalcium silicate-based Biodentine in comparison to white MTA and zinc oxide eugenol-based cement (ZOE). The materials assessed included White MTA, ZOE cement, and Biodentine. The data were analyzed using ANOVA and Tukey-Krammer post-hoc test. Biodentine presented the shortest initial and final setting time, radiopacity that does not agree with ISO 6876:2012 specifications, higher compressive strength after 21 days, and higher dentin bond strength in comparison to white MTA and ZOE. Both MTA and Biodentine produced an alkaline environment compared to ZOE. It can be concluded that Biodentine exhibited faster setting, higher long-term compressive strength and bond strength to the apical dentin than MTA and ZOE.

Adding MTA to water and propylene glycol at various concentrations produced a smooth mixture, as reported by Natu et al. [81]. However, adding reduces the water available for the hydration reaction, resulting in extended first-setting periods. This can lead to a longer wait time before restoring the tooth and increased solubility, impairing the material's sealing ability. On the other hand, PP.G. improves flowability, enhancing the root canal system's ability to adapt to abnormalities and increasing the material's capacity to infiltrate perforations. However, handling and injecting the mixture into the root canal may present new challenges. Bramante et al. [82], MTA and clinker with 5% calcium sulfate had the slowest initial and final setting times for Portland cement, respectively. MTA's initial setting time was significantly longer than other materials, which is concerning. The only factor that extended the setting time compared to pure clinker was the inclusion of 5% calcium sulfate. The 5% calcium sulfate clinker had a much longer final setting time. A cement designed for biomedical applications must be set and hardened under physiological conditions with high humidity. Experimental techniques have allowed the design of stable cement formulations that can be submerged in a liquid phase immediately after mixing, solving some applicability issues [83].

Biocompatibility

Dental materials must be biocompatible to avoid toxicity to living tissues, particularly when in contact with bone cells in the periapical region. Various filling cement with unique compositions are available, and biocompatibility studies have been conducted in vitro and in vivo. A new generation of in vitro study methods and filling cement has recently emerged[84]. The cement's biocompatibility is crucial for resolving pre-existing bone lesions or preventing inflammatory reactions in healthy bone tissues in the periapical region [39].

Bramante et al. [82] examined the inflammatory reaction, presence of foreign body giant cells, and tissue regeneration around the implanted materials (Portland cement clinker with or without 2% or 5% calcium sulfate, and MTA-CPM) after 15, 30, and 60 days. The inflammatory reaction was graded on a scale from 0 to 3, while the presence of foreign body giant cells and tissue regeneration were assessed qualitatively. The results were then compared and analyzed using statistical tests, such as ANOVA and Tukey's test, to determine the significance of the findings. The materials that showed less inflammatory reaction, fewer foreign body giant cells, and better tissue regeneration were considered more biocompatible. Inflammatory cells and blood vessels were few. Biodentine has better cytocompatibility with primary human osteoblasts than MTA, as seen by increased cell survival, adhesion, and proliferation. Human osteoblast-like cell line MG63 has shown similar biocompatibility to MTA and Biodentine; both promote survivability, bonding, and proliferation of MG63 cells. This may be because MTA and Biodentine have comparable heterogeneous morphology, surface roughness, and particle size [85]. MTA encourages Saos-2 cells to adhere, disseminate, proliferate, and secrete collagen.

According to Tanomaru-Filho [86], MTA increases ALP activity, calcified nodule development, osteogenic differentiation, and Saos-2 cell line differentiation. Widbiller et al. [87] evaluated the suitability of a new tricalcium silicate cement, Biodentine™, for use in dentistry by comparing its cytocompatibility and ability to induce differentiation and mineralization in three-dimensional cultures of dental pulp stem cells with mineral trioxide aggregate (MTA). The result showed that the cell viability was highest on the tricalcium silicate cement, followed by MTA, while viability on glass ionomer cement and dentin disks was significantly lower. Alkaline phosphatase activity was lower in cells on new tricalcium silicate cement compared to MTA, but the expression patterns of marker genes associated with mineralization were alike between the two materials. The results indicated that the new tricalcium silicate cement is cytocompatible and bioactive, confirming its suitability as an alternative to MTA in vital pulp therapy.

Regarding cytotoxicity, EndoSequence Root Repair Material and MTA show similarly low levels of cytotoxicity and cytokine expressions (IL-1b, IL-6, and IL-8). It was investigated by Fayyad [83] that two bioceramic-based materials, BioAggregate and iRoot (Innovative Bioceramix (IBC) Vancouver, Canada), showed acceptable biocompatibility and cytotoxic effects on human fibroblast MRC-5 cells, which was concentration-dependent). For the in vitro biocompatibility of White Pro-Root MTA and iRoot, iRoot was found to be biocompatible and did not cause any significant cytotoxic effects, even though it promoted significantly lower viability than MTA after 48 hours of exposure; iRoot did not cause any significant cytotoxic effects because cell viability was greater than 70% of the control group in most tests[88].

Bioactivity

Bioactive materials induce a desired host tissue response using biomimetic approaches; in tissue engineering, the term refers to the biomaterial's ability to induce cellular effects via active ions biologically and substances released from its surface. In contrast, in biomaterial science, the term describes the biomaterial's ability to form the mineral hydroxyl apatite on its surface in vivo and in vitro[89].

The elongated shape of human dental pulp stem cells (DPSCs) induces calcified deposition in the presence of MTA in a simulated pulp capping model, confirms MTA's excellent bioactivity, and justifies its use in pulp capping.

In a comparative study conducted by Luo et al., the bioactivity of Biodentine and iRoot FS was assessed concerning their interactions with human periodontal ligament cells (PDLCs). The investigation revealed that both Biodentine and iRoot FS elicited an enhancement in the adhesion of human PDLCs. Notably, iRoot FS exhibited a superior capacity in comparison to Biodentine for facilitating the viability, proliferation, and osteoblastic differentiation of human PDLCs [90].

Chang et al.[91] studied the bioactivity and biocompatibility of four root canal sealers (Sealapex (Kerr Corporation), MTA Fillapex, iRoot SP ARS (Dentsply-Sankin KK) better to understand iRootSP'ss bioactivity to human PDLCs. All the tested sealers proved safe for human PDLCs while boosting Alp activity and causing mineralization nodules to form. Dubey et al. [92]proposed using graphene nanosheets to enhance dental cement physicomechanical properties and bioactivity. Biodentine and Endocem Zr were tested with the addition of Gp-NSs and found to have increased hardness and decreased setting times without sacrificing any of their fundamental properties.

Radiopacity

Radiopacity is a fundamental property because, radiographically, it will allow the professional to verify the correct root canal filling by the filling materials showing the correct apical limit of obturation and future controls to ascertain the success of endodontic therapy [93].

This property became standardized for dental restorative materials with the ISO 6876–2012 standard, which established that these materials must have a radiopacity equal to or greater than the radiographic density of dentin, equivalent to 3 mm of aluminium. When the radiopacity of the restorative material is lower than that of dentin, the differential diagnosis through imaging is compromised [94].

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is lower than that of dentin, the differential diagnosis through imaging is compromised [8]. More recent studies on the radiopacity of cement have used digital radiography or digitized images [95-97] , as this digital radiography requires less exposure time and eliminates the stage of chemical processing, responsible for variations in image quality, in addition to allowing better observation of density and radiographic contrast. The substances in their composition define the radiopacifying characteristics [8]. Many factors, such as material thickness, X-ray beam angle, type of radiographic film or a digital system used, and changes in the powder-to-liquid ratio during material handling, can affect this response of luting agents, but their composition seems to be the most essential. Among the oxides most used for this purpose, bismuth oxide is present in the composition of MTA Angelus and Pro-Root MTA. However, several studies have shown that this radio pacifier can increase the porosity of MTA, consequently decreasing the compressive strength and altering the cement hydration process[98]. This oxide has also been pointed out as probable for the dental darkening verified for MTA in contact with dental structures [8].

Radiopacifier Additives in the Endodontic Bioceramics

The radiopacity of endodontic materials is a critical physical feature. Endodontic cement must have a radiopacity larger than 3.0 mm about the aluminium scale, as specified by the ISO 6876 standard[99]. According to ANSI/ADA standard no.57, all endodontic cement must be 2.0 mm more radiopaque than dentin or bone [100]. Biomaterials with low radiopacity may result in incorrect analysis.

Additionally, radiopacity is essential for some spinal compression fracture therapies involving cement injections. In this case, it is critical to correctly identify the biomaterial after application to avoid material leakage into the spine or veins [101]. Radiopacity is an essential property to determine the materials used in the root canal system, such as those used to treat vital organs and distinguish them from natural tissues[29]. Thus, a radiopacity agent must be added to EndoBinder (Binderware, Sao Carlos, SP, Brazil) to enable radiographic visualization of the cement and the quality of the root canal filling and differentiate the cement from neighbouring anatomic structures. The ideal radiopacity agent should be inert, contaminant-free, and nontoxic, and it should be supplied in the smallest amount feasible, without forgetting that this smallest amount must be constituted of elements with large atomic numbers. By adding a proper amount of particles containing heavy metals such as bismuth (Z=83), silver (Z=47), and zinc (Z=30), the radiopacity of the material may be altered [7, 102, 103]. Zinc oxide is a non-toxic component of dental materials used in prosthetic and implant dentistry. Specific formulations include zinc oxide impregnated with silver to boost its radiopacity. The disadvantage is that silver is prone to discolor dentine. This is a particular issue for the coronal access cavity and impairs the look of the tooth. Bismuth compounds have substituted silver in sealer formulations, a well-known radiopacifying agent[104]. MTA has a large amount of bismuth oxide and exhibits a high radiopacity due to this compound's X-ray absorption. Nonetheless, specific studies have shown that this addition might increase porosity and decrease the mechanical strength of samples made of cement[98]. Thus, creating a new cement component based on rare earth elements with a high radiopacity that aids in the hydration and setting of the cement might improve its use.

CONCLUSION

According to current scientific information, bioceramics are essential to endodontics advancements. This conclusion is based on the existing body of knowledge. Bioceramics often need to be improved to benefit from their unique properties. Antimicrobial and radio-opacifier agents, such as silver compounds and many trace elements, have been integrated into bioceramics, as described above. Scientists assess dentists'' treatment progress using a biocompatible combination in various treatment procedures. The effectiveness of the method was the primary focus of the investigations. Because of this, scientists were eager to investigate commercial bioceramic products in endodontics.

On the other hand, research has shown that changing market trends and the need for better patient outcomes are essential determinants of technological change. The advantages of the bioceramic cement based on the literature in this review started with similarity to biological tissue, improved biocompatibility, intrinsic osteoinductive capacity because they can absorb osteoinductive substances during bone healing, resorbable lattices provide a regenerative scaffold that dissolves as the body rebuilds tissue excellent hermetic seal, chemical bond, and radiopacity, and these properties are critical to biomimicry of lost tissue, for the term biomimetic endodontics. In contrast, precipitation in situ after setting resulted in bacterial sequestration, which was the reason for the limitation. The nanocrystals inhibit bacterial adherence in bioceramic powders with a 1-3 nm diameter. Fluoride ions may be found in apatite crystals, resulting in a nanomaterial with antibacterial characteristics. Solubilization of the repair may be compromised if the lead content or solubility is increased.

Tooth cracking may occur as a result of excessive bioceramic cement setting expansion. Biomineralization by the use of bioceramic cement is less successful. Developing new bioceramic formulations moves at a glacial pace, and more clinical research is urgently needed to speed things up. Healthy teeth are essential to overall health because teeth are the primary component of the oral cavity. Besides endodontics, bioceramics have also been used in surgical and prosthodontic procedures; its properties during endodontic formation can preserve a more tooth structure.

The main limitation of the current study is that most of the included studies are technical and laboratory preclinical studies. Laboratory studies present the preliminary results to improve clinical conditions. However, to guide the interpretation of the benefits offered by bioceramics, it should be noted that each test performed on these materials has limitations. Although the current studies are promising for these materials, whose clinical use has recently become widespread worldwide, long-term clinical results are lacking in the literature. Given all its benefits, they appear to have a bright future in dentistry. These materials have the potential to revolutionize endodontics with further research. There is a lack of data in this field to support the above-described and identified future research avenues for bioceramics in endodontics. However, conduct extensive clinical research on these scientific aspects in upcoming work.

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