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MESTRADO INTEGRADO EM MEDICINA DENTÁRIA

CONTRIBUTION OF BIOCERAMIC SEALERS AND RESIN-BASED ENDODONTIC CEMENTS IN ENDODONTICS

Trabalho submetido por

Mohamed Mounir Ibrahim

para a obtenção do grau de Mestre em Medicina Dentária

Julho de 2024

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Trabalho orientado por

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ABSTRACT

Bioceramic endodontic cements are endodontic materials made from ceramic particles. They are a class of materials derived from natural minerals or synthetically produced inorganic materials that exhibit excellent biocompatibility and bioactivity. They offer a range of potential advantages over traditional resin-based endodontic cements.

Resin-based endodontic cements are the most commonly used materials for root canal obturation. They consist of a binder, such as epoxy resin or acrylic resin, and a hardener, such as a conditioning agent, primer, or polymerization powder.

Bioceramics and resin-based endodontic cements contribute to the effectiveness of endodontic treatment. They help create a good seal , provide good compressive strength, and exhibit good biocompatibility . The objectives of this narrative review are: to describe the characteristics of bioceramics and resin-based endodontic cements; to describe the indications for both materials and their mode of application; and to compare the two materials in terms of their characteristics.

Key-words: Bioactive materials, bioceramics, conventional materials, resin-based endodontic cement

RESUMO

Os Cimentos biocerâmicos e os cimentos endodônticos à base de resina são ambas opções eficazes para a obturação endodôntica do canal radicular.

- Os Cimentos endodônticos biocerâmicos são materiais endodônticos feitos de partículas de cerâmica , eles são uma classe de materiais derivados de minerais naturais ou de materiais inorgânicos produzidos sinteticamente que apresentam excelente biocompatibilidade e bioatividade, eles apresentam uma série de vantagens potenciais em relação aos cimentos endodônticos tradicionais à base de resina.

-Os Cimentos endodônticos à base de resina são os materiais de obturação endodôntica mais comumente usados para obturação do canal radicular. Eles consistem em um ligante, como uma resina epóxi ou uma resina acrílica, e um endurecedor, como um agente de condicionamento, primer ou pó de polimerização.

Os biocerâmicos e os cimentos endodônticos à base de resina contribuem para a eficácia do tratamento endodôntico. Ajudam a criar um bom selamento , uma boa

resistência à compressão e boa biocompatibilidade .

Os objetivos desta revisão narrativa são: descrever as características dos cimentos biocerâmicos e dos cimentos endodônticos à base de resina; descrever as indicações para os dois materiais e comparar os dois materiais do ponto de vista das suas características.

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Palavras-chave: Materiais bioativos, biocerâmicas, materiais convencionais, cimento endodôntico à base de resina

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LIST OF ABBREVIATIONS

NF - French standard

ADA - American Dental Association.

ISO - International Organization for Standardization.

DCT - direct contact test

PH - Hydrogen Potential

MTA - Hydrogen Potential

ANSI - American National Standards Institute

ADA - American Dental Association.

SEM - Scanning Electron Microscope

BR - BioRoot™ RCS

CEM - Calcium enriched Mixture

I. Introduction

Nonsurgical root canal treatment can fail for various reasons, including the presence of intracanal and extracanal bacteria, inadequate shaping and cleaning of the canals, poor coronal sealing, untreated, unfilled, or overfilled root canal spaces, and iatrogenic errors(Thellend-Gauthier, 2022).

Factors that influence the success of endodontic treatment include the root canal morphology, the periapical status, the material and technique of obturation, and the endodontic sealers used.(Alsubait et al., 2018) The justification for retreatment is to regain access to all parts of the root canal system, followed by the removal of the obturating material which will facilitate thorough disinfection of the root canals.

A universally accepted "gold standard" obturation material currently used in endodontics is gutta-percha, with commendable properties of non-toxicity and biocompatibility(Vishwanath & Rao, 2019).It is entirely inert once obturated at the root canal level, thermoplastic by nature and re-identifiable. (Dobrzańska et al., 2021)

However, gutta-percha has failed to establish adequate seal due to the lack of adhesion of gutta-percha to the dentine of the canal wall. This drawback has highlighted the importance of incorporating sealers or cement during obturation, filling the spaces between the dentine of the canal wall and the interface of the obturating material. It can also be used to fill accessory canals, irregular canalities, and minor gaps(Camilleri, 2015).

Various adhesive obturation solutions have been developed with the aim of obtaining a "secondary monoblock" within the root canal, in which the core material, the sealer agent, and the root canal dentine create a single cohesive unit. (Belli et al., 2011)

Based on their chemical composition, sealers are divided into different groups.

Zinc Oxide-Eugenol (ZOE): A traditional sealer made from zinc oxide and eugenol oil. It has antibacterial properties but can discolor teeth and is somewhat brittle(Castro et al., 2023).

Calcium Hydroxide: This type of sealer contains calcium hydroxide, which helps to stimulate the formation of new dentin. However, it can be irritating to the tissues around the tooth(Desai & Chandler, 2009).

Glass Ionomer: These sealers are made from a combination of glass particles and polyacrylic acid. They release fluoride, which can help to prevent tooth decay, and bond well to dentin(Miyaji et al., 2020).

Silicone-Based: Silicone-based sealers are flexible and easy to use. However, they do not bond as well to dentin as some other types of sealers(Sebastian et al., 2021).

Resin-Based: Resin-based sealers are made from epoxy resins or methacrylates. They are very strong and have good adhesion to dentin. However, they can be technique-sensitive and more expensive than other types of sealers.(Miyaji et al., 2020).

Epoxy and amine pastes are the pastes used in epoxy-based sealers. Unlike the amine paste, which comprises 1-adamantanamine and TCD-diamine, the epoxy paste mainly comprises calcium tungstate and zirconium oxide5: e.g. AH plus. Due to their beneficial physicochemical characteristics (Rekha et al., 2023) and their antibacterial effect, they are widely used in clinical practice. However, when extruded into the periapical tissues, it does not resorb easily (Alhindi et al., 2023) and can cause a short-term inflammatory response (Murray, 2017).

Bioceramic-Based: A newer type of sealer made from calcium silicate or calcium phosphate. Bioceramic sealers are biocompatible and have adhesion to dentin. They are also supposed to stimulate the formation of new dentin. (H. Zhang et al., 2009)

"Bioceramic sealers" have been developed to seal canal spaces. These injectable, pre-mixed hydrophilic calcium silicate and phosphate-based sealer are composed of zirconium oxide, calcium silicates, monobasic calcium phosphate, calcium hydroxide, and a thickening agent. Bioceramic-based sealers use the naturally present moisture in the dentinal tubules to initiate and complete their setting reaction as they are hydrophilic and insoluble. Tubular diffusion is considered to be the process by which bioceramic-based sealers bond to dentin, resulting in mechanical interlocking, leading to bond formation, and the production of hydroxyapatite .

Sealers play a crucial role in reducing microleakage by filling the spaces between the root dentin and gutta-percha. Many in vitro and in vivo studies present inconsistent and ambiguous results regarding the proper selection of sealers, ultimately determining the treatment outcome. Epoxy-based sealers and bioceramic sealers have generally been suggested in surveys on different sealers (Najafzadeh et al., 2022) Assimilating all available information in the literature on these materials can help the practitioner to execute a successful endodontic therapy without void. Thus, this thesis aimed to describe the characteristics and compare bioceramic sealers and epoxy-based sealent

II. Development

1. Ideal Characteristics of a Root Canal Sealer

1.1. Definition of Canal Obturation

Canal obturation is the final stage of endodontic treatment, aimed at isolating the root canal system from the oral environment and the periodontium. This stage should promote apical and lateral root healing, preventing any recurrence of pathologies (Gasner & Brizuela, 2024).

1.2. Principle of Canal Obturation

The obturation of the root canal system involves isolating the main, secondary, and accessory canals from the rest of the body, respecting the boundary of the endodontium. This boundary is formed by the cementodentinal junction, located approximately 1 mm from the radiographic apex. Beyond this boundary lies the periodontium, which contains all the elements necessary for apical healing. Therefore, a hermetic obturation must isolate the endodontium from oral contamination. (Gasner & Brizuela, 2024).

1.3. Objectives of Canal Obturation

The objective of endodontic treatment is to eliminate or reduce the bacterial load below a threshold that does not trigger the appearance of an endodontic lesion.(Siqueira et Rôças, « Clinical implications and microbiology of bacterial persistence after treatment procedures », s. d.).

Canal obturation is currently the only method used in daily dental practice to maintain the result of endodontic disinfection achieved during canal preparation. This step in endodontic treatment aims to isolate the canal system from the oral environment and the deep periodontium by sealing the canal network that was instrumented in the previous stages, thus ensuring apical seal . (Siqueira et Rôças, « Clinical implications and microbiology of bacterial persistence after treatment procedures », s. d.) .

Therefore, this stage of treatment creates a favorable environment for apical and lateral root healing, preventing any recurrence of pathology.

1.4. Endodontic Sealers

In endodontics, it is important to understand the difference between a sealer and a cement.

1.4.1. Sealer

1.4.1.1. Definition:

A sealer is a substance primarily used to seal the space between the walls of the root canal and the main filling material (such as gutta-percha cones).

Its main role is to ensure a hermetic seal to prevent microbial infiltration (Libonati et al., 2021).

1.4.2. Cement

1.4.2.1. Definition:

A cement is a denser and more rigid material used to completely fill the space inside the root canal. It can serve as the main filling material or be used in conjunction with a sealer.

Dental cements traditionally come in the form of powders that need to be mixed with basic liquids to form a semi-thick solution. When applied, this solution hardens on the surface to form a brittle structure, strong enough to maintain shape, yet fragile enough to be replaced and removed as needed (Sakaguchi, R. L., & Powers, J. M. (2012). Craig's Restorative. Dental Materials, 161-198. - Search Results, s. d.) .

1.5. Classification Of Root Canal Sealer

Based on their principle ingredient:

1-Zinc oxide eugenol containing sealer.

2-Iodoform containing sealer.

3-Calcium hydroxide containing sealer

4-Resin containing sealer

5-Polyacrylic acid containing sealer.

6-Silicone based sealer

7-MTA based sealer.

8-Calcium-silicate-Phosphate containing bioc

9-Caleium-phosphate containing sealers.
(Zhekov & Stefanova, 2021)

1.5. Objectives of Endodontic Sealer

Endodontic cement should not be confused with canal filling paste. In fact, pastes are used to fill the canal system, whereas endodontic cement functions as a sealant between the gutta-percha and the canal dentin (*Cohen's Pathways of the Pulp*, 2020).

The endodontic cement must adhere to the gutta-percha and the canal dentin while meeting ISO 6876 (sealing material requirements) and NF EN26876 standards (*Cohen's Pathways of the Pulp - 9780323673037*, s. d.) .

In the 1980s, the American National Standards Institute and the American Dental Institute defined a number of standards to test new cements and ensure they meet several critical criteria. These tests, revisited in the early 21st century, are six in number: film thickness of the cement, setting time, flow, radiopacity, dimensional stability after setting. (American National Standards Institute & American Dental Institute, 1980s).

The first test must evaluate the film thickness of the cement through a solubility test, with the loss of mass being less than 3%. The second test must assess the setting time, which should not vary by more than 10% from the manufacturer's indication. The third test evaluates the flow based on ADA 57 and ISO 6876 tests. The difference between the two tests in their interpretation mainly lies in the validation criteria. In the ADA 57 test, after manipulation, the diameter of the cement disk at the end of the test (once all manipulations are completed) must be less than 25 mm to pass the test, whereas it must be less than 20 mm in the ISO 6876 test for validation. The fourth test must evaluate the radiopacity, which should be equivalent to 3 mm of aluminum. The fifth test must evaluate the dimensional stability after setting, which should be less than 1% shrinka upon setting and less than 0.1% expansion upon setting. Therefore, regardless of the canal sealing cement used, it is expected to meet the following specifications first outlined by Grossman. (Cohen's Pathways of the Pulp, 2016)

-Good adhesion to dental walls and the main filling material.

- Sealing: no setting shrinkage,

-Non-soluble in oral fluids,

-Viscosity suitable for filling accessory canals.

-Antiseptic, bacteriostatic.

- Does not cause tooth discoloration.

- Relatively slow hardening.

- Biocompatible: non-irritating, non-mutagenic, non-cariogenic, no immune reaction.

- Radiopacity.

- Must allow for re-treatment.

- Easy to handle.

Among these sealing cements is bioceramic, which we will discuss in our thesis.

2. Bioceramic Sealer in Endodontics

2.1. General Information of Bioceramics

Bioceramics are a class of biomaterials composed of ceramic materials specifically designed for medical and dental applications. They are known for their biocompatibility, bioactivity, and mechanical properties, making them suitable for a variety of clinical uses (Hench & Wilson, 1993). We can classifiy them by their properties and their medical employment:

- **By Properties:**

- **Bioinert Ceramics**: These materials, such as alumina and zirconia, do not interact with biological tissues. They are primarily used for their mechanical strength and wear resistance (Chevalier, 2006).
- **Bioactive Ceramics**: These include hydroxyapatite and certain calcium phosphates that can bond with bone and other tissues. They are used in applications where integration with the surrounding tissue is desired (Hench, 1991).
- **Bioresorbable Ceramics**: Materials like calcium sulfate and some calcium phosphates that gradually dissolve in the body, being replaced by natural bone (Dorozhkin, 2010).

- **By the material employment:**

- **Orthopedics**: Used in bone grafts, joint replacements, and coatings for metal implants to improve biocompatibility and osseointegration (Ducheyne & Qiu, 1999).
- **Dentistry**: Employed in dental implants, root canal sealers, and bone regeneration materials (Melo et al., 2013).

Calcium phosphate was first used as a bioceramic restorative dental cement by LeGeros et al (Geros et al., 1982). However, the first documented use of bioceramic materials as a root canal sealer occurred two years later when Krell and Wefel (K. F. Krell & Wefel, 1984)compared the effectiveness of an experimental calcium phosphate cement with Grossman's sealer on extracted teeth, finding no significant difference between the two sealers in terms of apical occlusion, adaptation, dentinal tubule occlusion, adhesion, cohesion, or morphological appearance.(K. V. Krell & Madison, 1985).

Nevertheless, the experimental calcium phosphate sealer failed to provide as effective apical sealing as Grossman's sealer. Chohayeb et al.(Chohayeb et al., 1987)later evaluated the use of calcium phosphate as a root canal sealer in adult dog teeth, reporting that the calcium phosphate-based sealer provided a more uniform and tighter adaptation to dentinal walls compared to gutta percha (chohyeb et al 1987).

Calcium phosphate cement has since been successfully used in endodontic treatments, including pulp capping, apical barrier formation, periapical defect repairs, and bifurcation perforation repairs (Chau et al., 1997) and there are two major advantages associated with the use of bioceramic materials as root canal sealers. Firstly, their biocompatibility prevents rejection by surrounding tissues. (Koch & Brave, 2009) Secondly, bioceramic materials contain calcium phosphate, which enhances the setting properties and results in a chemical composition and crystalline structure similar to tooth and bone apatite materials, there by improving the bond between the sealer and root dentin (Ginebra et al., 1997).

One of the most widely used bioceramics in dentistry is MTA, it was introduced by Dr. Mahmoud Torabinejad en 1993 comme matériau de réparation endodontique. After receiving approval from the Food and Drug Administration for clinical use, MTA was marketed by the company Dentsply in 1998 under the name ProRoot MTA®, which had a graycolor.

Initially developed for root perforations, it quickly found broader applications due to its excellent biocompatible and sealing properties.

In 2002, white MTA was produced and marketed by the same company to prevent discoloration caused by gray MTA (Shaik et al., 2021)

2.1.1 Trioxide Aggregate Mineral: MTA

2.1.1.1 Composition

75% of the composition of MTA consists of Portland cement components, namely:

- tricalcium silicates
- tricalcium aluminates
- tricalcium oxides
- silicate oxides

Bismuth oxide constitutes 20%, playing the role of an opacifying agent. The remaining portion is made up of gypsum. Gray MTA has the same constituents, but it additionally contains dicalcium silicates and aluminoferrite, which is responsible for its graycolor.

2.1.2 Physical and Mechanical Properties

2.1.2.1 Compressive Strength

- MTA has a compressive strength of 40 MPa after 24 hours, increasing to 67 MPa after 21 days (Dawood et al., 2017).
- This strength varies with the type of MTA, liquid nature and pH, and storage conditions.

2.1.2.2 Sealing

MTA demonstrates superior sealing properties compared to Super EBA®, IRM®, and amalgam, particularly in retrograde fillings, resisting bacterial penetration effectively (Pushpalatha et al., 2022).

2.1.2.3. Radiopacity

The radiopacity of MTA is equivalent to a 7.17 mm thick aluminium plate, due to the presence of bismuth oxide (Parirokh & Torabinejad, 2010).

2.1.2.4. pH

The pH of MTA starts at 10.2 after mixing, rising to 12.5 after 3 hours, which contributes to its biological properties (Parirokh & Torabinejad, 2010).

2.1.2.5. Solubility

The solubility of MTA is generally considered negligible but can increase over time depending on the powder/liquid ratio (Parirokh & Torabinejad, 2010).

2.1.3. Biological Properties

2.1.3.1. Antibacterial and Antifungal Properties

MTA is effective against facultative anaerobic bacteria but not strict anaerobes (Komabayashi et al., 2016).

It shows antifungal activity against Candida Albicans, which is concentration-dependent, peaking at 50 mg/ml (Parirokh & Torabinejad, 2010).

2.2. General Information of Bioceramics Sealer

The widespread acceptance and achievement of MTA stimulated more investigation and innovation in the field of bioceramic materials. The goals were to enhance the manipulation of the material, decrease the duration required for preparation, and maximize the effectiveness of the material's bioactive and antibacterial characteristics. These cements are utilized in several clinical scenarios, including pulp capping in both primary and permanent teeth, root-end filling, repair of perforations, and as an apical plug for teeth with open apices, due to their exceptional sealing capability and biocompatibility(Torabinejad et al., 2018). The inaugural endodontic sealer of this novel category, which was unveiled in 2007, was iRoot SP (Innovative Bioceramix, Vancouver, Canada). Subsequently, more products utilizing calcium silicates have been developed, and several categorizations have been suggested to differentiate this novel category of endodontic sealers from traditional sealers (Donnermeyer et al., 2019).

2.2.1. Propriete of Bioceramic Root Canal Selear

2.2.1.1. Biocompatibility

Biocompatibility is a crucial requirement for any canal sealing material, as it functions as an implant that comes into direct contact with vital tissues at the apical and lateral foramina of the root, or indirectly through surface restorations (Ørstavik, 2005). Biocompatibility refers to the ability of a material to elicit an appropriate and beneficial response from the body in specific contexts. Essentially, a material is deemed biocompatible if it does not cause adverse reactions such as toxicity, irritation, inflammation, allergy, or carcinogenicity when it contacts tissues (Sun et al., 1997). Most studies assess biocompatibility by analyzing cytotoxicity, which examines the material's effect on cell survival. The cytotoxicity of bioceramic-based sealers has been studied in vitro using mouse and human osteoblast cells, as well as human periodontal ligament cells (Human Periodontal Ligament Cell Response to a Newly Developed Calcium Phosphate–based Root Canal Sealer - Journal of Endodontics, s. d.).

The biocompatibility of most canal obturations based on bioceramics is primarily attributed to the inclusion of calcium phosphate in their composition. Given that calcium phosphate is a significant constituent of hard tissues like teeth and bones, scientific literature suggests that numerous bioceramic sealers have the potential to stimulate bone regrowth in situations where they are accidentally pushed out through the apical foramen during endodontic treatments or repairs of root perforations. (Bryan et al., 2010) .

2.2.1.2 Antibacterial activity

the primary cause of endodontic and periapical diseases is microbial in origin (Pertot, Machtou, & Simon, Endodontie). This is why we are interested in the antimicrobial activity of sealing cements.

Endodontic treatments aim to complement the chemomechanical cleaning process performed during the endodontic procedure. Colombo and colleagues (2016) conducted a study to evaluate the antimicrobial activity of six types of dental cements, including BioRoot RCS and TotalFill BC Sealer, against E. faecalis.

The results of the direct contact test (DCT) revealed strong antimicrobial activity of both bioceramic cements. It was observed that BioRoot RCS exhibited significantly higher antibacterial activity after 15 to 60 minutes of contact compared to the initial 6 minutes, whereas TotalFill BC Sealer showed significantly elevated antibacterial activity across all evaluated contact durations (Colombo et al., 2016).

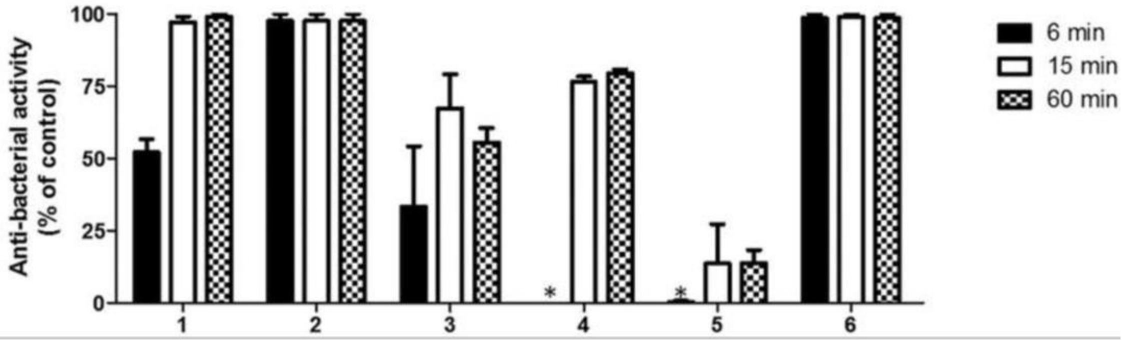


Figure1. Tests of the antibacterial activity of 6 materials: 1 Bio Root(RCS), 2Total Fill BC sealer,3 MTA Fillapex,4Sealapex,5 AH plus, 6 Easy Seal
Colombo et al., « Biological and physico-chemical properties of new root canal sealers », 2018

2.2.1.3. Biological Activity

Bioactivity can be defined as the ability of an organic substance or biomaterial integrated into a living organism to induce biological activity (Dimitrova-Nakov et al., "In vitro bioactivity of BiorootTM RCS, via A4 mouse pulpal stem cells"). Various research studies have highlighted the effectiveness of bioceramic cements, particularly in stimulating bone physiology and promoting mineralization of dental structure.

They promote the incorporation of calcium (Ca) and silicate (Si) into dentin, leading to the formation of a crystalline structure similar to apatite found in teeth and bones (Ginebra et al., "Setting reaction and hardening of an apatitic calcium phosphate cement").

.2.1.4. Solubility

Solubility refers to the mass loss of a material when immersed in water for a specific period. According to ANSI/ADA specifications, the solubility of an endodontic sealing cement should not exceed 3% of its mass (Al-Haddad & Che Ab Aziz).

However, Colombo et al. found higher solubility rates for BioRoot RCS and TotalFill BC Sealer compared to other tested sealing cements. These two sealers exhibited the highest solubility among the six tested sealing cements (Colombo et al., "Biological and physico-chemical properties of new root canal sealers").

High solubility in a root canal sealer could potentially lead to the formation of voids between the material and root dentin, creating pathways for leakage into the oral cavity and periapical tissues (Viapiana et al., 2014).

Orstavik emphasized that the solubility of a root canal sealer should not exceed 3% of its weight (Orstavik, 2005).

Vitti et al. reported that MTA-Fillapex has a solubility of less than 3%, complying with ISO 6876/2001 standards (Vitti et al.,).

Similarly, EndoSequence BC's solubility is reported to comply with ISO 6876/2001 standards (EndoSequence BC citation).

The low solubility of MTA-Angelus, meeting ANSI/ADA requirements, is attributed to a matrix of insoluble crystalline silica in the sealer that maintains its integrity even in the presence of water (MTA-Angelus reference).

2.2.1.5. Aesthetic Considerations

To maintain the desired appearance, it is crucial that a root canal sealer does not result in tooth discolouration. If residues are not removed from the coronal dentin in the pulp chamber, the chromogenic features of root canal sealers become more pronounced. Partovi et al. (2014) discovered that Apatite III Sankin showed very little discoloration after nine months of use, in contrast to AH26, Endofill, Tubli-Seal, and zinc oxide eugenol sealers. The most prominent darkening was found in the cervical region of the crown. Research has demonstrated that the use of MTA-Fillapex leads to negligible crown discolouration, to the point where it is not detectable in a clinical setting.. (Partovi et al., 2020).

2.2.1.6. Radiopacity

The radiopacity of root canal filling materials allows for the visualization and differentiation of these materials from adjacent anatomical structures. This facilitates radiographic control of the obturation process. According to ISO standards, the minimum value for the radiopacity of a root canal sealer is 3.00 mm Al.

According to Candeiro et al., the radiopacity of Endosequence BC Sealer (which has the same composition as TotalFill BC Sealer but a different trade name) is 3.83 mm Al, thus exceeding the required standards (Candeiro et al., 2012).

2.2.1.7. Setting Time

The ideal duration for polymerization of a root canal sealer should provide sufficient time for proper handling and manipulation. Nevertheless, the gradual process of polymerization might result in tissue irritation, as the majority of root canal sealers possess a certain level of toxicity prior to complete solidification. The manufacturers of EndoSequence BC Sealer and iRoot SP state that the polymerization reaction is catalyzed by the presence of moisture in the dentinal tubules. Although the typical duration for setting time is four hours, it can be considerably extended in individuals with excessively dry canals.(Xu et al., 2020).

According to the manufacturer of MTA-Fillapex, the setting time for this product is at least two hours, a claim confirmed by at least two studies (Viapiana et al., 2014; Camilleri et al., 2012). However, even shorter setting times (66 minutes) have been reported for MTA-Fillapex (Viapiana et al., 2014). The setting reaction of MTA material has been detailed by Darvell and Wu (Darvell & Wu, 2011)

2.2.1.8. pH Levels

Hydrogen Potential (pH)

The hydrogen potential, denoted as pH, is an index that measures the activity of hydrogen ions in a solution. It is an indicator of acidity, with a scale ranging from 0 to 14.

pH = 7: neutral solution

pH < 7: acidic solution

pH > 7: alkaline solution

According to Colombo et al. (2016), the pH of the two tested bioceramic cements, BioRoot RCS (listed as #1 in the table) and TotalFill BC Sealer (listed as #2 in the table), is highly alkaline, with values exceeding 10 for TotalFill and over 11 for BioRoot after 3 hours, and remaining high even after 24 hours.

Materials	pH	
	3h	24h
1	11.25 (1.12)	11.43 (0.07)
2	10.06 (1.24)	10.67 (1.25)

Table 1: pH measurements

Adapted from Colombo, M., et al. (2016). Biological and physico-chemical properties of new root canal sealers.

2.2.1.9. Sealing Properties

The sealing characteristics of endodontic cements can be assessed using measurements of wettability, viscosity, and film thickness. Research by Zhou et al. and Zhang et al. demonstrates the effective sealing properties of bioceramic cements, attributed to their appropriate viscosity and wettability, which facilitate the penetration of the cement into root canals.

3. Presentation of Some Bioceramic Sealers

Bioceramic sealers are advanced materials used in endodontics to seal the root canals after cleaning and shaping. These sealers are known for their excellent biocompatibility, antimicrobial properties, and ability to promote healing and regeneration of periapical tissues. Below are a few notable bioceramic sealers, along with their key features and clinical applications:

3.1. BioRoot™ RCS

Composition: BioRoot™ RCS is a calcium silicate-based sealer that includes tricalcium silicate, zirconium oxide, and calcium phosphate.

Figure 2 : Commercial Presentation of BioRoot™ RCS adapted from (Prüllage et al., 2016)

3.1.1. Properties:

Biocompatibility: BioRoot™ RCS has shown excellent biocompatibility, induced minimal inflammatory response and promoting healing.

Antimicrobial Activity: Studies have demonstrated its strong antimicrobial activity, particularly against E. faecalis (Colombo et al., 2016).

Bioactivity: This sealer stimulates the release of calcium ions, which can aid in the formation of hydroxyapatite, enhancing the healing process of periapical tissues (Dimitrova-Nakov et al.).

Setting Time: It has a working time of about 10 minutes and a setting time of around 4 hours.

Radiopacity: BioRoot™ RCS meets the ISO standards for radiopacity, making it easily visible on radiographs (Zhou et al., 2015).

Solubility: While it has a higher solubility than some other sealers, its ability to promote tissue regeneration offsets this disadvantage (Colombo et al., 2016).

3.2. TotalFill® BC Sealer

Composition: This sealer is also based on calcium silicate and includes zirconium oxide, calcium hydroxide, and filler agents.

3.2.1. Properties:

Biocompatibility: TotalFill BC Sealer is known for its excellent biocompatibility, causing minimal irritation to periapical tissues.

Antimicrobial Activity: The sealer has been shown to have a strong antimicrobial effect, particularly effective against common endodontic pathogens (Colombo et al., 2016).

Bioactivity: It is bioactive, encouraging the formation of hydroxyapatite upon setting, which aids in sealing the root canal system (Dimitrova-Nakov et al.).

Setting Time: The setting time is influenced by the moisture in the root canal system, typically around 4 hours under normal conditions.

Radiopacity: It exceeds the required radiopacity standards, allowing for easy monitoring and verification of the root canal filling (Candeiro et al., 2012).

Solubility: Despite having a higher solubility, it remains a preferred choice due to its overall performance and bioactivity (Colombo et al., 2016).

3.3. EndoSequence® BC Sealer

Composition: Similar to TotalFill BC Sealer, EndoSequence Sealer comprises calcium silicates, calcium phosphate, and zirconium oxide.

3.3.1. Properties:

Biocompatibility: EndoSequence BC Sealer exhibits excellent biocompatibility, promoting minimal inflammatory response and enhancing tissue healing (Colombo et al., 2016).

Antimicrobial Activity: It has demonstrated significant antimicrobial properties, particularly effective against resistant bacteria like E. faecalis (Colombo et al., 2016).

Bioactivity: This sealer supports the formation of a hydroxyapatite layer, which improves the sealing properties and enhances periapical healing (Dimitrova-Nakov et al.).

Setting Time: The presence of moisture in the root canal system catalyzes the setting reaction, with a typical setting time around 4 hours.

Radiopacity: It meets and exceeds the ISO standards for radiopacity, ensuring clear radiographic visibility (Candeiro et al., 2012).

Solubility: The solubility is within acceptable limits, though slightly higher, but it is compensated by its bioactive properties (Colombo et al., 2016).

3.4. MTA Fillapex®

Composition: MTA Fillapex is a mineral trioxide aggregate-based sealer, incorporating calcium silicates, salicylate resin, and natural resin.

3.4.1. Properties:

Biocompatibility: MTA Fillapex has been extensively studied for its biocompatibility, showing favorable outcomes with minimal tissue reaction (de Oliveira et al., 2018).

Antimicrobial Activity: It has moderate antimicrobial properties, effective against a range of endodontic pathogens (Komabayashi et al., 2016).

Bioactivity: Known for its ability to promote the release of calcium ions, which leads to the formation of hydroxyapatite and supports the regeneration of bone and dentin (Han & Okiji, 2013).

Setting Time: The setting time varies but typically ranges from 2 to 4 hours depending on the environmental conditions (Youssef et al., 2019).

Radiopacity: It has sufficient radiopacity, complying with ISO standards, ensuring it is easily distinguishable on radiographs (Parirokh & Torabinejad, 2010).

Solubility: MTA Fillapex has low solubility, maintaining its integrity over time and providing a durable seal (Parirokh & Torabinejad,

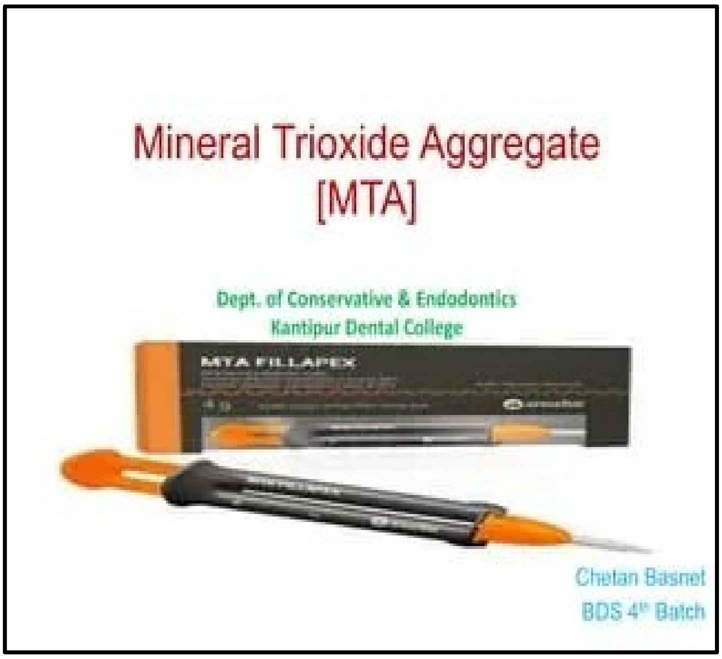


Figure3: Presentation commercial MTA FILLAPEX adapted from (Dental Advisor)

3.5 Endosequence BC sealer®.

3.5.1 Presentation

It is a canal sealing cement brought to the market by the American company Brasseler. It is composed of zirconium oxide, calcium silicates, di or tricalcium silicates, calcium phosphate, calcium hydroxide, and thickening agents. It is presented in a low-viscosity fluid form, injectable, and packaged in a syringe (fig.4) .

This cement is available in France under the name Totalfill BC sealer®.

Figure4 Commercial presentation of Endosequence BC Sealer® adapted from (Restorative - Brasseler USA Dental, n.d.).

3.6 .Calcium enriched Mixture

3.6.1. Presentation

It is also called NEC (New Endodontic Cement). It was introduced in 2006 by the Iranian team of Asgary (Utneja et al., 2015) It comes in the form of a powder/liquid mixture. The powder consists of:

- Calcium oxide (51.75%)
- Sulfur trioxide (9.53%)
- Phosphorus pentoxide (8.49%)
- Silica (6.32%)
- A minor amount of aluminum oxide, sodium oxide, and magnesium oxide. The liquid is a saline solution (Utneja et al., 2015)

Mechanical and physical properties

Setting time

- The setting of CEM occurs through a hydration reaction. It requires 50 minutes to set (Utneja et al., 2015)

4. The Resin-based Cements

.1. Generality

Resin-based root canal sealers are the latest addition in the category of endodontic sealers. They provide superior qualities when compared to traditional sealers, including - but not limited to - low polymerization shrinkage, adhesion to dentin and other core materials, resistance to dissolution in oral fluids, dimensional stability, and the ability to release therapeutic dental materials. Due to a variety of clinical and material-related factors, the choice of a sealer is important when one is considering the use of a resin-based sealer. This work presents a review of the resin-based sealers, which includes their classification, compositions, physical properties, bond strength, and the clinical application of resin-based sealers. (Antunovic et al.2021)

Endodontic sealers are placed in the root canal system of teeth between all of the points of the root filling material and the dentinal walls, and they play a critical role in preventing the reinfection of the root canal system. Resin-based root canal sealers are a new and advanced addition in the diverse group of endodontic sealers, providing various advantages such as good adhesion to dentin and core filling materials, dimensional stability, resistance to dissolution in oral fluids, and the ability to release therapeutic substances. This work aims to review the resin-based root canal sealers, such as their composition, classification, and properties (Álvarez-Vásquez et al.2024)

Resin-based root canal sealers can be classified into 4 families:

4.1.1. Methacrylate-based resin root canal sealers

4.1.1.1. First generation "Hydron®": polyhydroxyethylmethacrylate

Hydron® (Hydron, Canada) was introduced to clinical dentistry in the 1970s by Goldman et al., Rising et al., and Benkel et al. It was described as an ideal root canal filling material for the following reasons:(Ari et al., 2003, 2010)

- It is easy to use as an injectable product.
- It is non-irritating.
- It effectively obturates the canal system.
- It does not support bacterial growth.

However, recent reports have cast doubt on the nature of Hydron® (Hydron, Canada) as a root canal filling material. Tanzilli et al. (Sipert et al., 2005)demonstrated, using animal models, that Hydron® has a high degree of resorption. Additionally, Rhome et al. (Iohara et al., 2011)showed that it significantly exhibits a greater degree of leakage compared to other cements used with gutta-percha.(Sipert et al., 2005)

Hydron® (Hydron, Canada) became obsolete in the 1980s due to unacceptable clinical outcomes. Meanwhile, scientific research on dentin bonding was still in its early stages of development. The use of poly 2-hydroxyethyl methacrylate or poly HEMA as a major ingredient contributed to this progress.

This highly hydrophilic sealer was developed as an injectable root canal cement after the addition of a catalyst (benzoyl peroxide). Following its commercialization, a significant discrepancy emerged between the manufacturer's claims and clinical observations regarding its physical and clinical properties, as well as its biocompatibility.

Research results have been far from favorable, especially in the presence of severe inflammatory reactions due to the continuous release of residual monomer, percolation, water absorption, and swelling in contact with moisture (Shrestha et al., 2010)If it hardens in a humid environment, it swells uncontrollably, and its polymerization is heterogeneous.(Rahimi et al., 2009; Shrestha et al., 2010)

On the other hand, this material contracts during dry polymerization, potentially resulting in a comparatively less hermetic obturation of the canal walls(Ezzie et al., 2006)

A comparative study showed that root canals obturated by vertical condensation with Hydron® (Hydron, Canada) exhibit more frequent sealing defects than canals obturated with other pastes. Hydron® (Hydron, Canada) is partially resorbable, a characteristic demonstrated through implantation trials on rat teeth and histological studies on dog teeth(Schäfer E, 2000). While some studies indicate good compatibility of Hydron® with tissues, others show that it generates inflammatory reactions in the subcutaneous tissues of rats and can induce and sustain inflammatory processes in the periapical tissue, leading to periapical bone resorptions.(Schafer E, 2000)

Cell culture experiments have also revealed significant cytotoxicity of this root canal sealer. Indeed, Hydron® (Hydron, Canada) causes approximately 94% inhibition of metabolism just after mixing and 59% after polymerization. In a prospective clinical study, the condition of periapical tissue after 5 years in root canals obturated with Hydron® (Hydron, Canada) was radiologically judged to be poorer than that of tissue in canals obturated with other pastes.

AH26® (Dentsply). Moreover, Hydron® (Hydron, Canada) is neurotoxic in proximity to nerve fibers. In conclusion, the use of Hydron® (Hydron, Canada) is not recommended.'

4.1.1.2. Second generation

Sealers in this class do not require etching or the use of dentin adhesive. They are inherently hydrophilic. EndoRez® (Ultradent Products, Inc., South Jordan, UT) is the most notable cement of this generation.

Figure 5: Commercial Presentation of EndoREZ® System adpted from (*EndoREZ® Ultradent*, s. d.)

It is a hydrophilic, two-component material (base and catalyst), self-etching

Base	Catalyst
Diurethanedimethacrylate. *Triethylene glycol trimethacrylate. *Abismuth compound for radiographic opacity. *Small amounts of other fillers. *A peroxide initiator. *A photo-initiator.	* Diurethane dimethacrylate *Triethylene glycol trimethacrylate. *A bismuth compound opaque to X-rays. *Small amounts of other fillers.

Table 2 : Composition of the Endorez cement®: (da Silva Neto et al., 2007)

The sealer can be used with gutta-percha or with a resin coating (Resilon® (Resilon Research, Madison, CT)), the latter with the aim of establishing continuous adhesion (monoblock) between all materials.

The manufacturer recommends that, after preparing the root canal walls, the dentin should remain slightly moist to maximize the hydrophilic properties of the sealer, allowing the resin to penetrate the dentinal tubules and form a hybrid layer with collagen fibers. However, excessive water can lead to water permeability during the polymerization process and disrupt bonding with an increase in microbial microleakage.

This sealer is radiopaque and has low viscosity, playing a crucial role in ease of handling and making it useful for placement in both wide and narrow root canals. It provides good adaptation to the complexity of dentin walls. EndoRez® (Ultradent) bonds well to the canal walls but not to gutta-percha, which represents a potential weakness and a path for bacterial leakage. To address this issue, resin-coated gutta-percha cones (Gutta EndoRez®) have been introduced.

The combination of this root canal cement with resin-coated gutta-percha cones results in the formation of a monoblock, and that is why the sealing properties of this system are superior. The goal of EndoRez® (Ultradent) is to establish a tight seal while ensuring maximum leakage resistance.

Gutta EndoRez® cones can be used with an accelerator, which speeds up the

polymerization reaction of EndoRez® (within 4 to 5 minutes), allowing for a quicker establishment of a monoblock.

EndoRez® (Ultradent) is known to be well-tolerated by connective tissues and bone tissue. Although it is reported to exhibit minimal cytotoxic effects in the first 3 weeks following its placement in the root canal, this cytotoxicity gradually decreases over time.

For the EndoRez® (Ultradent) system, only a hydrophilic methacrylate resin-based sealer is used for coupling gutta-percha cones with a resin coating to dentin. The increased hydrophilic nature of EndoRez® (Ultradent) enhances its penetration into tubules exposed by the recommended use of (EDTA) as the initial rinse and the use of NaOCl as the final irrigation product. (Herbert et al., 2009)

While EndoRez® (Ultradent) exhibits acceptable apical sealing, its coronal sealing can be improved with the use of a self-etch adhesive. Endodontically treated canals should be sealed both coronally and apically to prevent the penetration of microorganisms and oral fluids. (Santos et al., 2010)

The immediate or delayed preparation of the root canal space for a post has no impact on the sealing of a canal obturated by the EndoRez® (Ultradent) system.

According to the manufacturer, the EndoRez® accelerator can be used for rapid polymerization. Implementation of the EndoRez® accelerator is done by immersing either gutta-percha cones or Gutta EndoRez® cones in the accelerator, followed by immersion of these cones in the unpolymerized EndoRez® (Ultradent), accelerating the polymerization.

A reduction in the volume of EndoRez® (Ultradent) is expected due to polymerization shrinkage, which is beneficial for the seal and tightness(Schäfer E, 2000).

According to a 2008 study by Funda et al., there was no significant difference in apical leakage values when using or not using the EndoRez® accelerator(Schäfer E, 2000).

The following table summarizes the results of this study.

Groups (n = 10)	Mean ± Standard Deviation, Lp ($\mu L/cmH_2O/min^{-1}$
1: EndoREZ A(−) immediate	2.77 ± 0.79^a
2: EndoREZ A(+) immediate	2.88 ± 1.38^a
3: EndoREZ A(−) 1-week	19.95 ± 7.85^c
4: EndoREZ A(+) 1-week	6.20 ± 2.09^b

*** $p < 0.05$,A(+):WithacceleratorA(-)Without accelerator**

Table 3 : Values of apical leakage using the EndoRez® accelerator system, immediately and long-term after root canal obturation. Adpted from (Schäfer E, 2000)

Through the chemical bond between Gutta-percha and the EndoRez® (Ultradent) resin, a bond is formed (Fig6):

- 1st Interface: Between Gutta-percha and resin coating.
- 2nd Interface: Between resin coating and sealing cement.
- 3rd Interface: Between the sealer and the dentin hybrid layer.

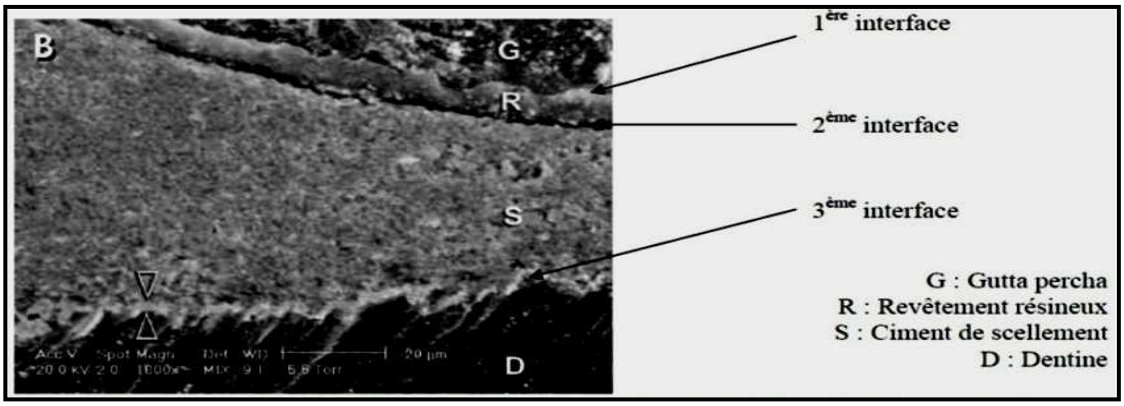


Figure 6 : Scanning Electron Microscope (SEM) photograph at x1000 magnification of a section of the EndoRez system. (Eldeniz&Ørstavik, 2009a)

Table 5 : Properties of EndoRez® (Ultradent) Cement: (Schafer E, 2000; Sipert et al., 2005).

Physiques	Chimiques	Biologiques
Couleur: Pink for the cones, white for the cement base, and colorless for the catalyst. **Adhérence à la dentine:** good through the cement	the cones and the cement are soluble in chloroform.	Biocompatibility: Very good. The cones and the cement are well-tolerated by human tissues and exhibit minimal cytotoxicity.
Thermal conductivity: "like Gutta-percha. However, even though the Endorez® system can be used with all obturation techniques, warm vertical condensation is not the preferred technique		
Radio-opacity: identical to Gutta-percha.		
Rigidity: The cement is slightly more ductile than dentin, which facilitates retreatment.		
Polymerization inhibition: Similar to the Resilon® system (Resilon Research, Madison, CT), the presence of an oxygen layer inhibits polymerization and can thus affect the final properties of the material.		

4.1.1.3. Third generation

Third-generation sealers are self-etching sealers that utilize self-etching acid primers beyond the layers of smear layer on canal walls, partially demineralizing the underlying root dentin to achieve micromechanical retention. A moderately fluid composite is then applied as a sealer on the primed dentin. (Clinton & Van Himel, 2001; Doyle et al., 2006)

4.1.1.3.1. Epiphany®(Pentron Clinical Technologies, Wallingford, CT)

It is a resin-based cement composed of a self-etching primer and an adhesive. It isused with Resilon® cones. The Epiphany® system (Pentron Clinical Technologies, Wallingford, CT) is compatible with mostendodontic instruments (NiTi, Protaper®, Heroshaper®...). Resilon/Epiphany® can be easily removed using solvents, manually, and with rotary instruments, along with the application of heat. (Clinton & Van Himel, 2001; Cobankara et al., 2008)

The Resilon/Epiphany® system forms an intimate monoblock with the canal walls (Figure 6: a and b).

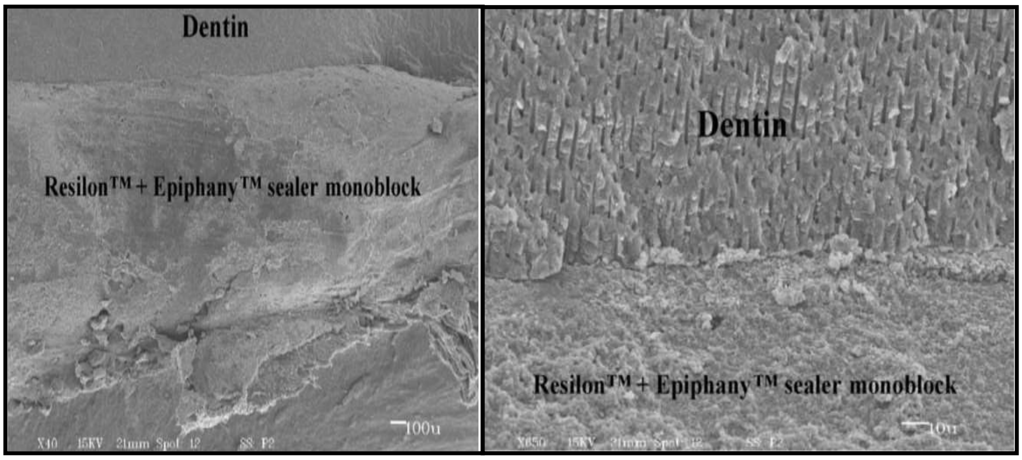


Figure 7 a: SEM view at "low" magnification showing the intimate shape of Resilon® cone (Resilon Research, Madison, CT), canal wall, and Epiphany/Resilon® (Resilon Research, Madison, CT).

Figure 7 b: SEM view at higher magnification showing the interface between Resilon® (Resilon Research, Madison, CT), Epiphany®, and dentin.

Epiphany® (Pentron Clinical Technologies) is the cement most capable of providing greater retention and sealing of obturation due to its demineralizing and self-etching potential, allowing the elimination of the detrimental dentin mud layer that is harmful to sealing.(Clinton & Van Himel, 2001; Cobankara et al., 2008)

Table 6 : The properties of Epiphany®(Pentron Clinical Technologies):

Physic	Chimic	Biological
"Color of the Resilon® cone (Resilon Research, Madison, CT): Slightly pink."99 "Density: 2.0 g/cm³ (at 20°C)." "Adhesion to dentin: Yes. Thanks to the Epiphany® system. Formation of a hybrid layer with dentin and adhesive that then bonds to the cone through copolymerization: This creates a true monobloc." Thermal conductivity: Slightly better than that of Gutta-percha. Resilon® (Resilon Research, Madison, CT) softens with heat. In vertical warm condensation, within a distance of 1 to 3 mm from the heat source, the temperature is 2°C higher for Resilon® (Resilon Research, Madison, CT) compared to Gutta-percha. Polymerization is accelerated by heat. For these reasons, warm vertical condensation is recommended. Melting temperature: between 70 and 80°C." "Radiopacity: Very significant. Thanks to the barium sulfate content in the cone and adhesive. • Greater radiopacity than AH 26® (DENTSPLY) and dentin. • Meets the minimum requirement for radiopacity and surpasses other radiographic	**Solubility:** • Resilon is insoluble in water • soluble in chloroform."	**Sterilization:** Immersing the cones in 2% ClONA or chlorhexidine is sufficient for sterilization. However, it appears to alter the surface of the cones. "Biocompatibility: The cytotoxicity of Resilon® (Resilon Research, Madison, CT) is equivalent to that of gutta-percha. It is considered moderate." Biodegradability: Weakness of Resilon® (Resilon Research, Madison, CT) as the ester linkage of Polycaprolactone can be cleaved by enzymes present in saliva.

sealers by a wide margin. • Epiphany® can be easily discerned on an X-ray. [19,14] Rigidity: Resilon® cones (Resilon Research, Madison, CT) are as flexible as Gutta-percha cones. Polymerization shrinkage: Yes. It is a major issue (8.1% on average according to Balguerie E). Polymerization inhibition: The presence of ClONA in the canal affects polymerization because oxygen inhibits the free radical of the monomer. • Final canal rinse with EDTA, chlorhexidine, or physiological saline is recommended. Wettability:Meets ADA 57 and ISO 6876 standards.		

4.1.1.3.2. RealSeal® (SybronEndo, Orange, CA):

RealSeal® (SybronEndo, Orange, CA) possesses dual characteristics. It iscomposed of urethanedimethacrylate (UDMA), poly dimethacrylate (PEGDMA), bisphenol-A dimethacrylate (BIS GAMA), barium borosilicate, barium sulfate, bismuth oxychloride, calcium hydroxide, and photoinitiators. It has the advantage of reducing infiltrations and improving fracture resistance. It is highly opaque. It is relatively sticky when heated, making its placement somewhat complicated.(Cobankara et al., 2008; Thibodeau, 2009)

4.1.1.4. Fourth generation

Fourth-generation sealers are further simplified, ensuring adhesion to dentin walls by incorporating acidic monomers into the resin-based sealer, making it self-adhesive to radicular dentin. (Doyle et al., 2006; Rahimi et al., 2009)

This family included the following products:

4.1.1.4.1.MetaSeal®

MetaSeal® (Sun Medical, Tokyo, Japan) also has the ability to adhere to radiculardentin and solidfillingmaterial (Resilon® cone or Gutta). This coatingis a hydrophilic self-etchingmaterial due to the inclusion of the acidmonomer 4-methacryloxyethyl trimellitate anhydride (4-META), which can diffuse through the demineralized surface to form the hybrid layer afterpolymerization. However, due to the presence of this radical in the acid composition, the cytotoxicity of MetaSeal® (Sun Medical, Tokyo, Japan) is high in the first week and willdecrease over time(Eldeniz&Ørstavik, 2009). MetaSeal® (Sun Medical, Tokyo, Japan) has lessfluidmovementwithlateral and vertical condensation techniques compared to Thermafil® and Ultrafil® techniques(Bodrumlu et al., 2007). MetaSeal® (Sun Medical, Tokyo, Japan) remainsseverelytoxicduring the first week and becomes non-cytotoxic by the end of the thirdweek(De-Deus et al., 2009).

4.1.1.4.2. Hybrid Root Seal®

Hybrid Root Seal® (Sun Medical, Tokyo, Japan) can be used with Resilon® cones (Resilon Research, Madison, CT) or Herofill® posts, but the first combination allows much less microleakage than the combination with Herofill® posts. (De-Deus et al., 2009)

4.1.1.4.3. RealSeal SE® (SybronEndo, Orange, CA)

Due to its self-etching and adhesive properties, RealSeal SE (SybronEndo, Orange, CA) does not require the use of a etchant, primer, or adhesive, and it is used with Resilon cones. The material is packaged in a dual-barrel syringe, one for the catalyst and the other for the base and can be mixed using a tip."

Automix attached to the syringe, or it can also be hand-mixed on a paper pad. A recent in vitro study (Ari et al, 2010) on the root of bovine incisors demonstrated that the use of this material reduces marginal microleakage compared to zinc oxide eugenol and epoxy resins .(Ari et al., 2010)

4.1.2. Epoxy resin-based cements

4.1.2.1. AH 26®(Dentsply)

Schroeder presented in 1954 the first example of this group of root canal sealers, AH26® (A: Ethoxyline base / H: Hexamethylene tetramine / 26: test number). These sealers exhibit excellent hermeticity and dimensional stability, with AH26® (Dentsply) showing initial expansion during cross-linking. It is an epoxy resin in powder and liquid form. The mixture of powder and liquid produces a root canal filling material with excellent sealing properties due to its adhesive characteristics and setting even in the humid conditions of the oral cavity(Barek S, Rilliard F, Delzangles B, 1999). It exhibits bio-inert behavior after polymerization. AH26® can easily penetrate into lateral canals and shows a polymerization shrinkage of less than 0.5%. Different studies have shown that AH26® presents irritative effects due to formaldehyde release. However, the intensity of this inflammatory reaction decreases during the first twenty days. (Barek S, Rilliard F, Delzangles B, 1999)

4.1.2.2. AH Plus®

This is a two-component paste/paste root canal sealer. AH Plus® (Dentsply, DeTrey, Konstanz, Germany), an epoxy resin, contains zirconium oxide and iron oxide, contributing to its increased radiopacity. (Regan et al., 2002)

"Wettability of a dental material is one of the most important handling properties. Firstly, when favorable, it results in easy mixing. Secondly, the filling material must be easily introduced into the root canal and exhibit some stability. Therefore, AH Plus® (Dentsply) has been designed to be slightly thixotropic. The epoxy resin-based sealer AH Plus® (Dentsply) and AH26®, have shown higher bond strength to dentin than zinc oxide eugenol, glass ionomer, and calcium hydroxide-based root canal sealers."(Rached-Junior et al., 2009)

	AH 26®	AH Plus®
Shape	Powder/liquid	Pasta/paste
Radiopacity	Significant	Very Significant
Solubility	Very Low	Very High
Discoloration	Partially	No
Releasing formaldehyde	YES	NO
Compatibility	Good	Excellent
Disobturation	Mechanics	yes

Table 7 : Properties of AH 26 and AH Plus Cements.

AH26® exhibits antibacterial activity that is significant during the first 24 hours and then decreases over time to reach its minimum on the 7th day. AH Plus® (Dentsply) is effective against E. Faecalis (Abi Rached-Junior et al., 2009).

4.1.3. Polyvinyl Resin-Based Sealers: (Scarparo et al., 2009)

The sole representative of this group is the Diaket® root canal sealer (ESPE, Seefeld, Germany):itwas first described as early as 1951. This mixture of vinyl polymer hardens through the formation of non-water-soluble cyclic complexes but is soluble in some organic solvents. Diaket® (ESPE, Seefeld, Germany) has proven to be cytotoxic in tests with human gingival fibroblast cultures and rat pulp cells, and neurotoxic in studies on the rat phrenic nerve. It is abandoned due to its biologically unacceptable properties

4.1.4. Composite Resin Sealers:

The sole representative of this group is the Acroseal® (Septodont, France): (EMERY, 2002).

Composition	"Properties"	"Characteristics"
Base (TCDDiamine, radio-opaque excipient) Catalyst ($CaOH_2$, DGEBA, radio-opaque excipient)"	"Root canal sealing cement based on $CaOH_2$ and epoxy resin."	• Insolubility in water, which enhances its sealing ability. • Perfect adhesion to the canal walls and gutta-percha surface, thereby reducing the risk of reinfection. • Low viscosity, making it easier to fill accessory canals. • High biocompatibility. • A resin matrix rich in $CaOH_2$. • Free of eugenol, making the cement compatible with adhesive coronal obturation techniques. • Chemical polymerization, which significantly reduces shrinkage after setting. • High radiopacity.

Table 8 : Properties of Acroseal® Cement (Septodont, France**)**

"Other sealers calcium hydroxide-based:

Sealapex® (Kerr®): (Thibodeau & Trope, 2007)

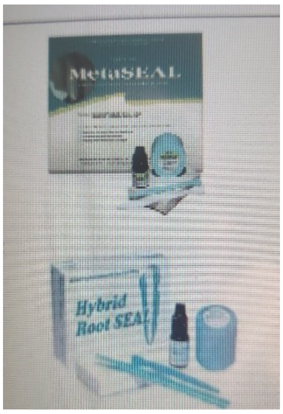
It is presented in the form of a paste: Base + catalyst.

- Composition: Calcium oxide (25%), Barium sulfate (20.4%), zinc oxide (6.5%), Silica particles less than a micron (3%), Zinc stearate (1%).
- The mixture is obtained after spatulation for 15 to 20 seconds of equal quantities in length or weight of base and catalyst.
- The setting time is 40 minutes at 37 °C and at 100% relative humidity.
- It exhibits very low setting contraction.
- The major drawback is its low dimensional stability.

<table>
<tr><td rowspan="2">Methacrylate-based resin</td><td>1sGeneration
Hydron®(Hydron,Canada) : discontinued due to its poor biological properties.</td></tr>
<tr><td>2nd Generation: EndoREZ® (Ultradent)

• Hydrophilic.
• Base/catalyst.
• Used with Gutta-percha cones, EndoREZ Gutta or resilon cones
3rd Generation:
RealSeal® (SybronEndo, Orange, CA):


• Dual-cure.
• Significant sealing capability.
Highly radiopaque
4th Generation:</td></tr>
</table>

	MetaSeal® (Sun Medical, Tokyo, Japan): • Self-etching. • Hydrophilic. Hybrid Root Seal® (Sun Medical, Tokyo, Japan): • Used with gutta-percha cones or Herofill posts. • Self-etching.  RealSeal SE® (SybronEndo, Orange, CA): • Base/catalyst. • Self-etching. • Does not require primer: • self-adhesive. • Used with Resilon cones. 
Epoxy resin-based	**AH 26® (Dentsply):** • Base/catalyst. • Very good dimensional stability. • Good sealing properties. • Releases formaldehyde. 
	AH Plus® (Dentsply): • Paste/paste. • Biocompatible, no formaldehyde release. 

	MM Seal®: • Base/catalyst. Auto-mixing syringe. • Used with gutta-percha cones. • Good sealing properties. 
Polyvinyl resin-based	**Polyvinyl resin-based Diaket®** (ESPE, Seefeld, Germany) • Cytotoxic Abandoned
Resin composite cement	**Acroseal®** (Septodont, France): • Base/catalyst. • Insoluble in water, providing better sealing. • Low viscosity. • High radiopacity. 

Table 9 : Different classes of resin cements:

5. Comparative Studies

As mentioned above, an ideal root canal sealer must meet the following requirements: biocompatibility, solubility, radiopacity, antibacterial activity, and sealing properties. To establish a comparison between the two materials, various comparative in vitro and in vivo studies have been conducted.

The current trend is to use more biocompatible and bioactive materials. This has led to the research and utilization of new bioceramic-based sealers. To date, the new bioceramic-based sealers do not possess the same favorable mechanical properties as epoxy resin-based sealers (Najafzadeh et al., 2022a).

5.1. Comparison of the two types of sealer

In comparative studies of the physical and chemical properties of three epoxy resin-based sealers and three bioceramic-based sealers conducted by n comparative studies of the physical and chemical properties of three epoxy resin-based sealers and three bioceramic-based sealers conducted by Lee and collaborators in South Korea in 2016, several observations were made. Epoxy resin-based sealers are preferred in clinical settings due to their resistance to resorption and dimensional stability., several observations were made. Epoxy resin-based sealers are preferred in clinical settings due to their resistance to resorption and dimensional stability (J. K. Lee et al., 2017)

According to Lee and collaborators in 2016, their study comparing the physical and chemical properties of bioceramic and resin-based sealers revealed several key findings. MTA Fillapex had the highest flow, while BC Sealer had the lowest. The setting times of the evaluated sealers differed from those indicated by the manufacturers, with AH-Plus having the longest setting time due to its specific chemical composition. In terms of radiopacity, all tested sealers met international standards, but AH-Plus and EndoSeal MTA demonstrated significantly higher radiopacity. Regarding dimensional changes, all sealers showed expansion relative to their initial dimensions, with AD Seal exhibiting significantly more expansion compared to the others. (J. K. Lee et al., 2017)

.Finally, the pH of the bioceramic-based sealers was significantly higher than that of the epoxy resin-based sealers over 24 hours, which may have implications for their biocompatibility and ability to influence hard tissue formation. BC Sealer, in particular, demonstrated a prolonged high pH, which could potentially cause damage to periapical tissues. In summary, this study highlights the importance of considering multiple aspects of endodontic sealers to ensure their clinical efficacy and safety. (J. K. Lee et al., 2017)

5.2. Comparison of Biological Properties

5.2.1 Biocompatibility

Several studies have evaluated the biocompatibility of various endodontic sealers using cytotoxicity tests with human gingival fibroblasts as target cells. These studies show low cytotoxicity and thus good biocompatibility for Bioroot RCS and TotalFill BC Sealer, which is superior to other tested sealers such as AH Plus and Easy Seal. (Colombo et al., 2018)

According to Colombo et al. (2018), their study compared the biocompatibility of several endodontic sealers, including Bioroot RCS, TotalFill BC Sealer, AH Plus, and Easy Seal. The results demonstrated that Bioroot RCS and TotalFill BC Sealer exhibited low cytotoxicity and high biocompatibility. These findings indicated that Bioroot RCS and TotalFill BC Sealer were superior in biocompatibility compared to AH Plus and Easy Seal, making them preferable choices for clinical application

(Colombo et al., 2018)

. A recent study by Vanessa Valente Elias and collaborators in 2024 aimed to evaluate the inflammatory tissue response induced by two types of endodontic sealers, BioRoot™ RCS (BR) and AH Plus Jet (AHPJ), when implanted in the subcutaneous tissue of mice. The researchers hypothesized that the inflammatory response to BR would be less severe than that to AHPJ. To test this, they conducted an in vivo study using isogenic mice, where the sealers were implanted through standardized surgical procedures. The inflammatory response was assessed by microscopic analysis and von Kossa reaction around the implants after 7, 21, and 63 days. A zinc oxide-eugenol sealer (ZOE) was used as a positive control, and a group without sealer served as a negative control (n = 10 per group and per period). The main results are as follows:

1. **At 7 days**: All sealers triggered an inflammatory response. BR showed a higher number of inflammatory cells and a thicker fibrous capsule compared to AHPJ, but both were less inflammatory than ZOE.
2. **At 21 days**: BR continued to provoke a more intense inflammatory response than AHPJ, with a thicker fibrous capsule than ZOE.
3. **At 63 days**: The inflammatory response of BR decreased, reaching a fibrous capsule thickness similar to that of AHPJ and ZOE. BR promoted intense calcium precipitation throughout the study.

Both AHPJ and BR sealers were ultimately biocompatible with the subcutaneous tissue of mice after 63 days, with AHPJ showing a better early inflammatory response, while BR demonstrated a potential for bioactivity (Elias et al., 2024).

5.2.2. Antibacterial Activity

These studies of Colombo and al demonstrate that BiorootRCS Sealer exhibit significant antibacterial activity, surpassing that of several other endodontic sealers suchas AHPlus, and EasySeal.

The author conclude that this antimicrobial activity of bioceramic sealers may be due to their alkaline pH (pH > 7). (Colombo et al., 2018)

5.2.3 Bioactivity

Studies have shown that bioceramic sealers actively stimulate bone physiology and the mineralization of dentin structures. They facilitate the incorporation of calcium (Ca) and silicate (Si) into the dentin, leading to the formation of a crystalline structure similar to dental and bone apatite (Dimitrova-Nakov et al., 2015a).

Dimitrova-Nakov et al., show that bioceramic cements are active, particularly in stimulating bone physiology and the mineralization of dentin structure.(Dimitrova-Nakov et al., 2015b).

5.3.Physicochemical Properties

5.3.1. Sealing Properties

The studies by Zhou et al. and Zhang et al. Zhou et al., (W. Zhang et al., 2009a)demonstrate that bioceramic sealers exhibit good sealing abilities due to their appropriate viscosity and wetting properties, which facilitate the cement's progression within the root canals.

A study conducted by Najafzadeh and colleagues used 82 premolars extracted due to caries and gum disease to compare bioceramic and epoxy resin-based sealers in terms of marginal adaptation and tubular penetration depth with different obturation techniques (Najafzadeh, Fazlyab, & Esnaashari, 2022). Two types of sealers were used: an epoxy resin-based sealer (AH-Plus, Dentsply, Germany) and a bioceramic sealer (Endosequence BC sealer).

The results showed that marginal adaptation and tubular penetration depth were significantly superior with the use of the bioceramic sealer compared to the other sealer types in the coronal, middle, and apical regions ($P < 0.001$). Neither the filling method nor the interaction between the type of sealer and the technique impacted marginal adaptation and tubular penetration depth across all studied regions (Najafzadeh, Fazlyab, & Esnaashari, 2022).

5.3.2 Solubility

According to the ANSI/ADA Specification standards, the solubility of an endodontic sealer should not exceed 3% of the mass. However, Colombo et al. found that BioRoot RCS exhibited higher solubility than AH PLUS.Colombo et al., (Colombo et al., 2018)

5.3.3 Radio-opacity

When comparing bioceramic cement with resin-based cement in terms of radiopacity, studies have shown that both types of sealers generally meet the ANSI/ADA Specification standards. However, bioceramic cements tend to exhibit lower radiopacity compared to resin-based cements. This difference in radiopacity may influence the ease of detection and interpretation of the root canal filling material on radiographs. While bioceramic sealers may require adjustments in radiographic exposure settings for adequate visualization, they still provide sufficient radiopacity for clinical use. Therefore, dentists need to consider this difference when selecting and interpreting endodontic materials for root canal treatments(Candeiro et al., 2012).

5.3.4 PH

When comparing the pH levels between bioceramic and resin-based cement, notable differences emerge. According to Colombo et al., the pH of the tested bioceramic cements, BioRoot RCS and TotalFill BC Sealer, is significantly alkaline. TotalFill BC Sealer exhibits a pH greater than 10, while BioRoot RCS surpasses a pH of 11 after 3 hours, maintaining elevated levels even after 24 hours. In contrast, resin-based cements typically exhibit lower pH levels compared to bioceramic counterparts.(Zhou et al., 2013)

5.4 Mechanical properties

5.4.1 Adhesion

Some studies suggest that bioceramic cements may offer better adhesion than resin-based cements in certain situations. This could be due to various factors such as chemical composition, physical properties, and the ability of cements to interact with dentin surface. Overall, bioceramic cements are often considered to provide satisfactory adhesive properties for root canal obturation. Weller et al., (Weller et al., 2008)

The result of most studies is that bioceramic-based sealers have better physical properties, sealing ability, adhesion, marginal adaptation, biocompatibility, and antimicrobial properties than epoxy resin-based sealers (Rekha et al.2023).

Bioceramic cements offer a number of advantages, including improved biocompatibility, better adhesion and the ability to stimulate bone healing. However, they do not yet have all the optimal mechanical properties of epoxy resin cements (Shahi etal.,2011).

6. Comparaison of the pain after obturation with bioceramic and resin based sealers

Several studies have compared the pain experienced after root canal obturation

with bioceramic and resin-based sealers. The results of these studies have been mixed. Some studies have found that bioceramic sealers are associated with less pain than resin-based sealers, while others have found no significant difference between the two types of sealers (Graunaite et al., 2018) .

In 2021 study was conducted to compare the effects of Endoseal MTA and AH Plus on postoperative pain and obturation time in root canal treatments. Patients with anterior teeth or premolars were assigned to group 1, while those with molars were assigned to group 2. Root canals in groups 1En and 2En were sealed with Endoseal MTA using the single-cone technique, whereas groups 1AH and 2AH used AH Plus with the continuous wave technique. Over a 7-day postoperative period, patients recorded their pain intensity at rest and while biting. The results showed no significant difference in the incidence or intensity of postoperative pain between the two sealers. However, Endoseal MTA required less time to seal the root canals, especially in molars. This indicates that while both materials are equally effective in managing postoperative pain, Endoseal MTA is more efficient in terms of application time.

(Shim et al., 2021)

In 2023, a study conducted by Marcelo Augusto Serón and his collaborators found, after a meta-analysis, that pain decreases with bioceramics within the first 24 hours (Serón et al., 2023).

Overall, the evidence on the pain-reducing effects of bioceramic sealers compared to resin-based sealers is inconclusive , more research is needed to determine whether bioceramic sealers are truly superior to resin-based sealers in this regard.,here is a table summarizing the results of some of the studies that have compared the pain experienced after root canal obturation with bioceramic and resin-based sealers:

Study	Compared Sealers	Postoperative Pain Results
(Graunaite et al., 2018)	Bioceramic vs Resin-based	No significant difference
(Shim et al., 2021)	Bioceramic vs Resin-based	No significant difference
(Serón et al., 2023)	Bioceramic vs Resin-based	the pain decreases with bioceramics within the first 24 hours

Table 8: summarizing the results of some of the studies

It is important to note that these studies were conducted with different populations, using different types of root canal obturation techniques and different pain assessment methods. Therefore, it is difficult to draw any firm conclusions about the overall pain-reducing effects of bioceramic sealers compared to resin-based sealers.

Within the limitations of this study, there was no significant difference in the incidence of postoperative pain after root canal treatment using bioceramic sealers compared to resin-based root canal sealers (Graunaite et al., 2018)

Also, the results of the eligible studies showed no significant association between sealer extrusion and the occurrence of postoperative pain, irrespective of the type of sealer used. Further studies are required to justify the results obtained in this study, to increase the accuracy, and to determine the causes of postoperative pain after endodontic treatment in several pulpal and periodontal conditions(Mittal et al., 2024).

7. Disadvantages of Bioceramic Sealers and Resin-Based Cements

7.1. Bioceramic Sealers

Referring to certain studies, we will name a few bioceramics

7.1.1.BioRoot™

according to studies by Vanessa Valente Elias et al. (2024) RCS

- **Disadvantages** :

Initial Inflammatory Response: BioRoot™ RCS (BR) showed a higher number of inflammatory cells and a thicker fibrous capsule compared to AH Plus Jet (AHPJ) after 7 days. This indicates a more intense initial inflammatory response, which can delay healing (Elias et al., 2024).

Long Setting Time: The longer setting time of bioceramic sealers can be a disadvantage in clinical handling, as it may prolong the duration of procedures (Colombo et al., 2016).

Additionally, bioceramic cements are not without drawbacks. Here are two common disadvantages of both BioRoot® RCS and TotalFill® BC Sealer, as well as one specific to each:

Interaction with Sodium Hypochlorite: BioRoot® RCS can experience an altered setting reaction when in contact with sodium hypochlorite. Sodium hypochlorite is crucial in endodontic treatment for thoroughly disinfecting the canal system. Therefore, it is recommended to rinse with saline solution before drying the canal system to avoid this issue (Camilleri et al., 2020) .

Difficulty in Retreatment: Both TotalFill® BC Sealer and BioRoot® RCS present challenges in endodontic retreatment. The possibility of removing these sealers for prosthetic reasons, such as an inlay-core type restoration, cannot be considered in the same session due to their often-lengthy setting times (Hess et al., 2011).

7.1.2. Endosequence BC Sealer

According to studies Najafzadeh, Fazlyab, & Esnaashari (2022)

- **Disadvantages** :

Solubility: Although bioceramic sealers have many advantages, some can exhibit higher solubility over the long term, which could affect their durability and the integrity of the seal (Najafzadeh et al., 2022).

Cost: Bioceramic sealers tend to be more expensive than resin-based cements, which can be a limiting factor for their widespread use (Dimitrova-Nakov et al., 2015).

7.2. Resin-Based Cements

7.2.1. AH Plus

- According to studies of Najafzadeh, Fazlyab, & Esnaashari (2022)
- **Disadvantages** :

Potential Toxicity: Resin-based cements can release unpolymerized monomers that may be toxic to surrounding tissues. This potential toxicity can induce an inflammatory response (Najafzadeh et al., 2022b)

Shrinkage: Resin-based cements can undergo shrinkage during the polymerization process, which can compromise the marginal seal (W. Zhang et al., 2009b).

7.2.2. AH Plus Jet

- **Disadvantages** :

Less Bioactivity: Compared to bioceramic sealers, resin-based cements show less bioactivity, meaning they are less capable of promoting healing and tissue regeneration (Lorang, s. d.).

Lack of Long-Term Adhesion: Resin-based cements may not adhere as well to dental structures in the long term compared to bioceramics, which can lead to sealing failures over time .(Colombo et al., 2018)

While bioceramic sealers have bioactive properties and promote tissue regeneration, they can exhibit disadvantages such as a more intense initial inflammatory response and higher cost. Resin-based cements, despite easier handling and good initial performance, can pose risks of toxicity and shrinkage, as well as lack of long-term bioactivity

III. Conclusion

Endodontic sealers are used to achieve fluid-tight sealing throughout the canal system [. An ideal canal sealer must provide excellent sealing once set, dimensional stability, sufficient setting time to ensure working time, insolubility against tissue fluids, good adhesion to canal walls, and biocompatibility

The market offers many types of endodontic sealers, which are categorized according to their chemical composition. These categories include zinc oxide-based sealers, eugenol-based sealers, sealers containing calcium hydroxide, resin-based sealers, glass ionomer-based sealers, silicone-based sealers, and bioceramic-based sealers. Schroeder introduced epoxy resin-based sealers in the field of endodontics and current modifications of the original formula are widely used for root canal obturation procedures .

Resin-based cements are another commonly used type of canal filling material. They also have several advantages, including:

• Ease of use: Resin-based cements are easy to mix and place in the root canal.

• Adhesion: Resin-based cements adhere strongly to dentin, the internal wall of the root canal. This allows for creating a tight and solid seal.

• Radiopacity: Resin-based cements are radiopaque, meaning they can be seen on radiographs. This allows the dentist to verify the placement of the canal filling.

Recently, bioceramic-based materials have revolutionized modern endodontics. As repair materials or sealing cements, it is now possible to push the boundaries of conventional endodontic techniques. The emergence of new bioactive materials has opened new horizons in endodontics and now appears to provide a safe and predictable solution to clinical situations that were previously considered challenging and unclear.

New bioceramic sealing cements such as BioRoot and Endosequence BC Sealer® are increasingly being used in the final canal obturation step. Unlike other endodontic sealing cements, their setting reaction occurs in a wet environment by exploiting the moisture of dentinal tubules. The solubility of these cements seems not to exceed 3%, which is interesting, in addition to their antibacterial action and their bioactivity in inducing the formation of tissue close to cementum. However, the major drawback of these new bioceramic cements remains the difficulty of their removal during retreatment of root canal therapy with traditional techniques.

Recent advances in bioceramics and resin-based cements have significantly enriched the field of endodontics. Bioceramics, such as BioRoot and Endosequence BC Sealer®, offer a promising alternative for canal obturation, thanks to their ability to exploit the moisture of dentinal tubules, low solubility, antibacterial properties, and bioactive capacity to promote the formation of cementum-like tissue. However, their removal during retreatment remains a major challenge. In parallel, resin-based cements have notable advantages such as ease of use, strong adhesion to dentin, and radiopacity, enabling effective sealing and precise monitoring. It is worth noting that research in this field is ongoing, and new information may become available in the future.

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