



Microleakage in Root Canal Obturation: A Narrative Review of Contemporary Sealers and Obturation Techniques

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ABSTRACT

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Root canal obturation plays an essential role in the long term success of endodontic treatment by preventing apical and coronal microleakage, which is one of the primary causes of endodontic failure. The new advancements in root canal sealers and obturation techniques have led to the improvement of sealing ability, biocompatibility and the adaptation to canal walls. This review evaluated the available evidence concerning the sealing ability of current endodontic sealers and the influence of different obturation techniques on microleakage. The evidence indicated that bioceramic sealers exhibited superior sealing performance, greater dentinal tubules penetration, better adaptation compared with conventional resin based sealers. Bioactive glass based sealers such as guttaflow bioseal can demonstrate favorable sealing ability with bioactive properties. While warm obturation techniques may lead to better adaptation and distribution, single cone obturation combined with bioceramic sealers also achieved comparable sealing properties. Nevertheless, substantial methodological heterogeneity among studies, including differences in leakage assessment methods, obturation protocols and sealer types which may limit direct comparison. Currently the studies suggest that modern bioactive glass based, bioceramic sealers give promising results according to root canal sealing. However, a more standardized and clinically relevant investigations are mandatory to establish definitive recommendations concerning the optimal sealer and obturation technique combined for long term success.

1. Introduction

The primary objective of obturation of root canal is to achieve a hermetic seal that blocks the entry of microorganisms and their by-products into the root canal system. Apical microleakage is one of the main causes of endodontic failure, accounting about 59% of failure cases as reported by Ingle. The amount of leakage is prejudiced by several factors, including chemical and physical properties of obturation materials, the obturation techniques and the presence or absence of smear layer [1]. These considerations underscore the importance of using root canal filling materials capable of establishing an effective seal between the

root canal system and the surrounding periapical tissues. Consequently, the evaluation of microleakage has become an essential approach for assessing the sealing performance and clinical effectiveness of endodontic materials. [2].

A wide variety of root filling materials and techniques are now available and the standard practice in endodontic therapy is a combination of gutta-percha points and root canal sealers [2]. Nowadays sealers classified up to seven types that are used in root canal obturation and these classification based on their chemical composition such as zinc oxide eugenol-based sealer, mineral trioxide aggregate (M.T.A) based sealer, silicone-based sealer, epoxy-based sealers,

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calcium hydroxide-based sealer, bioceramic based sealer, and glass ionomer-based sealer(GIC). AH-Plus® (AH Plus Jet, Dentsply Sirona), which is based on epoxy resin that has great sealing properties and was considered to be the gold standard against which all new sealers and bondable root canal filling materials had to be compared [3]. Several studies have been carried out to compare the sealing property of various sealers and some of them showed that the resin-based sealer provided a better seal than other sealers [4].

In recent years, a new root canal filling material tricalcium silicate-based root canal sealers have received significant attention due to their favorable physicochemical properties [5]. These sealers are biocompatible and nontoxic [6]. Another advantage of these materials is the ability to form hydroxyapatite during the setting procedure as well as their interaction with the dentin (infiltration of the mineral content of bioceramic-based sealer into the intertubular dentin) and forming the so-called mineral infiltration zone [7]. TotalFill® BC is one of the calcium silicate-based root canal sealers that have appeared on the European market. In Canada, it has been available for several years as iRoot® BC Sealer (Innovative Bioceramix, Inc., Vancouver, Canada), and in the USA as EndoSequence® BC Sealer (Brasseler USA, Savannah, USA) [8]. BC sealer absorbs humidity from dentinal fluid during setting which helps in setting reaction in the root canal without previous mixing. TotalFill BC Sealer has demonstrated cytocompatibility, bond strength and dentin penetrability [7].

Another new root canal sealer containing calcium silicate is GuttaFlow® Bioseal, also recognized as GuttaFlow 3, which was developed in 2015 and was launched to the market in 2016. This material is composed of gutta-percha, polydimethylsiloxane, zirconium oxide, platinum, and bioactive ceramic glass [9]. Therefore this review aimed to evaluate the current evidence regarding the sealing ability of contemporary endodontic sealers and the effect of different obturation techniques on

microleakage, with particular emphasis on resin-based, bioceramic-based, and bioactive glass-based sealers.

2. Endodontic treatment.

The objectives of treatment of the root canal are help in canal disinfection and prevent the microorganisms that delay the healing of the periapical area. Obturation, which is the multidimensional sealing of the whole root canal system is one of the important steps in endodontic procedure which aimed to [10]. Entrap bacteria that remained within root canal, Preventing the penteration of periapical tissue fluid into the canal space while also minimizeing both coronal and apical leakage.

Consequently, treatment outcomes are largely influenced by the complete elimination of infection and contamination within the plup space.

3. Microleakage:

The 3D obturation and complete apical and coronal seal is one of the major objectives of root canal treatment. Thus, achieving a proper seal is essential for ideal clinical outcomes, as it prevents microleakage in endodontic cases. Despite advancements in obturation materials and techniques that enhance the predictability of success, clinical failures can still occur [11].

Microleakage is the diffusion of bacteria, by-products , oral fluids, ions and molecules into the root and obturation material interface. Marginal gaps around an obturation material permit bacteria to pass into the root [10]. **(Jafari and Jafari, 2017).**

The failure of the root c anal treatment may be due to several factors, but apical microleakage is one of the major factors with a percent of 60% [2]. while is affected by several factors, including the obturation techniques, chemical and physical characteristics of obturation materials and smear layer removal and retention. Even with the chemico

mechanical preparation microleakage still active inside the dentinal tubules. Therefore, perfect apical sealing is necessary to avoid the remaining bacteria and their endotoxins from reaching the root apex [12].

4. Effect of Sealers on sealing ability:

The lack to adhesion of gutta percha to root canal wall is one of the drawbacks of its properties and because of this, a sealer utilized to get 3D seal, and to obturate the interface between the canal walls and the gutta percha. They also occupy the voids between gutta-percha cone during lateral condensation and adapt to anatomical complexities, such as lateral and accessory canals. Many kinds of sealers are available, and each type of sealer has its own properties some may have antibacterial qualities, others bond differently, but all aim to minimize leakage. Penetration of sealers and gutta-percha into dentinal tubules has been exhibited when the canal wall smear layer is removed[13]. The extent of penetration of root canal sealers into dentinal tubules has been used to determine the improvement of sealing ability to root canals during the introduction of new root filling materials and techniques [14].

Root canal sealers have a vital job in endodontic obturation by filling voids, accessory canals, and apical ramification, enhancing the adaptation of the core filling material to the root canal walls, and facilitating obturation through their lubricating effect. They may also contribute to the elimination of residual microorganisms. Given their biological significance and clinical relevance, continuous efforts have been made to optimize the physicochemical properties of root canal sealers [15].

Root canal sealers along with the solid core are the key role in achieving the hermetic seal by filling the accessory canals, voids, spaces and irregularities. Each one of the sealer has its own advantages and disadvantages [16].

Accordingly, the new root obturation materials that claim improvement of their

seal of the root canal system may be classified by function into those that[13].

- _ Establish adhesion to both dentine and root filling materials, thereby reducing interfacial gaps.
- _ Provide a self seal effect by undergoing slight expansion upon setting.
- _ Facilitate optimal flow and adaptation of the filling material to root canal walls.
- _ Support seal integrity through the formation of bioactive reaction products capable of repairing compromised interface.

4.1. Resin based sealers (AH Plus)

Resin-based sealers are extensively utilized in endodontic treatment owing to their favorable clinical performance and predictable sealing ability. Their excellent flow characteristics facilitate penetration into the dentinal tubules, enhancing micromechanical retention and adaptation to the canal walls. Based on their chemical composition, resin-based sealers are broadly classified into two categories: epoxy resin-based sealers and methacrylate resin-based sealers. [5].

In an attempt to overcome the inability of gutta-percha to adhere to dentine and its insufficient flow to canals ramification, Epoxy resin-based sealers have been commonly used with gutta-percha because they act as glue due to their adhering ability to canal wall dentine with good flow property having a deeper penetration into the dentinal tubules [1].

AH Plus is a two-paste epoxy resin-based sealer that sets through a polymerization reaction between epoxy resins and amine hardeners. The epoxide paste contains bisphenol A diglycidyl ether (a diepoxide), radiopaque fillers, and other additives, whereas the amine paste consists of three different amine compounds, silicone oil, and fillers. Owing to its excellent physicochemical properties, AH Plus is frequently regarded as the gold standard for

comparison with newly developed sealers. Its favorable long-term dimensional stability, low solubility, and high bond strength to root canal dentin have been attributed to the formation of covalent bonds between the epoxy groups of the resin and the amino groups of collagen following epoxide ring opening. [17]. This sealer shows better apical seal compared to others which makes it to be used as a control material in research[18]. This sealer was proven to have better penetration into root canal irregularities, due to its long setting time and flowability, thus increasing its micromechanical bond to root's dentin [19]. However, it lacks the ability to bond with gutta-percha, probably allowing leakage at this interface [20].

Shrinkage occurs during polymerization of commercially available epoxy resin sealer, but it can be relieved by the slow setting of the material through the resin flow and sorption of water from the wet dentinal tubules resulting in hygroscopic expansion and stress relief [21].

4.2. Bioceramic-Based Sealers

To improve the marginal seal, a latest-generation of hydrophilic root canal sealers has been developed with the advancement of bioceramic technology in endodontics. These sealers utilize the intrinsic moisture present within the dentinal tubules to initiate and complete their setting reaction. Unlike conventional sealers, bioceramic-based sealers exhibit minimal or no setting shrinkage, thereby promoting a gap-free interface between the gutta-percha cone, the sealer, and the root canal dentin. Furthermore, bioceramic sealers are bioactive and capable of forming hydroxyapatite at the sealer-dentin interface, which facilitates chemical bonding to the dentinal walls and enhances the sealing ability[22].

Bioceramic materials have been given an interest because of their ability in tissue regeneration and repair which is the reason of its given name. Owing to their interaction with biological tissues, they are

categorized as either bioactive or bioinert. The main benefits of these sealers are their biocompatibility, which promotes favorable tissue responses and minimize inflammatory reactions when they come in contact with living periapical tissues. In addition, these materials are capable of forming hydroxyapatite during setting reaction, thereby establishing a chemical bond at the dentin-sealer interface. Other favorable properties is the alkaline pH, antibacterial activity, radiopacity, dimensional stability, low toxicity, and chemical stability under physiological conditions. Despite these advantages, their removal during nonsurgical retreatment can be challenging once the material has fully set, representing one of their main clinical limitations [23]. Based on their principal constituents, commercially available bioceramic sealers can be categorized as MTA-based sealer, Calcium silicate-based sealer and Calcium phosphate-based sealer.

A typical sealer should provide strong adhesion to the dentinal walls, excellent sealing ability, and high biocompatibility to ensure long-term clinical success. Bioceramic sealers have attracted considerable attention because they exhibit many of these desirable characteristics and have demonstrated promising results in improving the obturation quality. Despite these advantages, traditional bioceramic-based sealers are associated with several clinical limitations, including relatively high cytotoxicity before complete setting, difficult handling characteristics, prolonged setting time, and dependence on sufficient environmental moisture to complete the hydration reaction. Furthermore, their high alkalinity during the setting process may influence the surrounding environment. Another important drawback is the difficulty of removing the material during nonsurgical retreatment once it has fully set, which may complicate retreatment procedures [15,24]. In order to overcome these disadvantages, manufacturers developed a next-generation bioceramic based root canal sealer based on previous medically reliable Bioactive Glass-Based Root canal sealer [25].

The theories of the mechanisms for the calcium silicate-based sealers are [15].

- (1) A mechanical interlocking bonds by dentinal tubular penetration of the sealer particles.
- (2) Establishing of a mineral infiltration zone by denaturing the collagen fibers with the strong alkaline sealer after the infiltrate of the sealer's mineral content into the intertubular dentin.
- (3) Hydroxyapatite is formed within the mineral infiltration zone through the hydration reaction of calcium silicates in the presence of dentinal moisture. This process involves the interaction of phosphate ions with calcium silicate hydrate gel and calcium hydroxide.

4.2.1 Calcium silicate-based sealer (BC sealer)

This calcium silicate-based sealer is marketed as EndoSequence BC (Brasseler, Savannah, GA, USA), iRoot SP (Innovative BioCeramix Inc., Vancouver, BC, Canada), in European is TotalFill® BC Sealer (FKG Dentaire, La Chaux de Fonds, Switzerland). This sealer is a mixture of nanosphere components mainly calcium silicate (tricalcium silicate, dicalcium silicate), calcium hydroxide, monobasic calcium phosphate, and a radiopacifier similar to white MTA [26]. According to the manufacturer, this sealer is supplied as a premixed, injectable paste formulated with a water-free thickening vehicle. Its hydrophilic nature enables the material to utilize the moisture present within the dentinal tubules to initiate and complete the setting reaction, thereby eliminating the need for manual mixing before clinical application. Additionally, this sealer is insoluble, aluminum-free, and could chemically bond to dentine during the setting process via hydroxyapatite formation via the infiltration of the mineral content of bioceramic-based sealer into the intertubular dentin and forming the so-called mineral infiltration zone [27]. The hydrophilic property of this sealer promote it to expand, thus increasing the total seal of root canal

system with the aforementioned chemical bonding[28].

4.3. Bioactive Glass-Based Root Canal Sealer

GuttaFlow Bioseal (GFB) is one of this type of sealer. After these innovations several studies tried to evaluate the interfacial characteristics between the hardened bioactive glass-based sealer and the root canal dentin by field-emission scanning electron microscopy (FE-SEM) and energy-dispersive X-ray spectroscopy (EDX). FE-SEM analysis verified the formation of tag-like structures composed of spherical, petal-like crystals extending into the dentinal tubules and covering their orifices. EDX analysis confirmed that these crystalline deposits consisted predominantly of hydroxyapatite (HAp). Based on these findings, a bonding mechanism has been proposed in which the bioactive glass-based sealer releases calcium and silicate ions that promote hydroxyapatite precipitation at the sealer–dentin interface. The newly formed hydroxyapatite penetrates the dentinal tubules and establishes a chemical bond with the dentinal walls, resulting in enhanced interfacial adaptation and improved sealing ability. After the obturation of a root canal with Bioactive Glass Based sealer, these sealer makes contact with a small amount of dental fluid on the dentin [25].

As the sealer set, the ions released from Bioactive glass sealer matrix which serve as the bioactive phase of the sealing past. Releasing these ions retains pH around 10 in the surrounding dentinal fluid, which is the ideal pH for the formation of hydroxyapatite on the surface of Bioactive Glass. Upon contact with dentinal fluid, the bioactive glass (BG) component of the sealer undergoes surface dissolution, releasing soluble Si, Ca, P, and Na ions into the surrounding environment. The released silica species condense to form a silica-rich gel layer on the BG surface, which functions as a nucleation template for calcium phosphate deposition. Subsequent crystallization of this calcium phosphate

results in the formation of a hydroxyapatite (HAp)-like layer on the bioactive glass surface and at the sealer–dentin interface. This biomineralization process promotes chemical bonding to dentin, enhances interfacial adaptation, and contributes to the long-term sealing ability of the root canal

filling system. Finally, hydroxyapatite-like crystal tags grow into dentin tubules. The overall Bioactive Glass based sealer bonding with the dentin wall is created through the formation of these hydroxyapatite layers and tags within the dentin tubules[25]. (Figure 1).

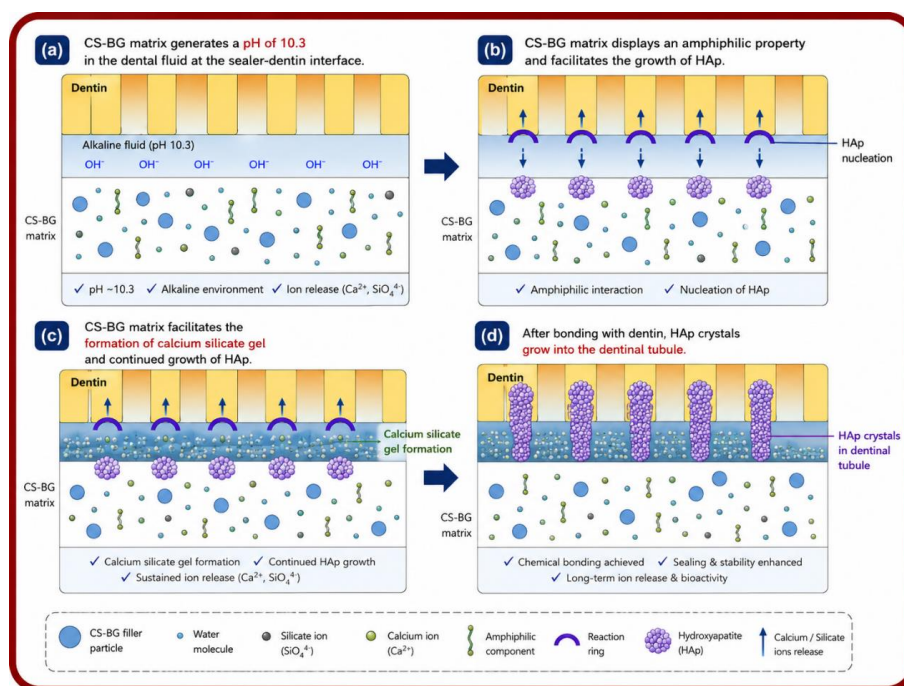


Figure 1: Illustration of the proposed interaction between calcium silicate–bioactive glass (CS-BG) sealer and dentin. (a) The CS-BG matrix creates an alkaline environment (pH ≈ 10.3) at the sealer–dentin interface. (b, c) This amphiphilic matrix promotes the nucleation and subsequent growth of hydroxyapatite (HAp). (d) As mineralization progresses, HAp crystals infiltrate the dentinal tubules, reinforcing the interfacial bond with dentin.

4.3.1 GuttaFlow Bioseal

GuttaFlow Bioseal (Coltene/Whaledent, Altstätten, Switzerland), also known to as GuttaFlow 3, is a premixed silicone-based root canal sealer introduced in 2015 and launched to the market in 2016. It consists of finely ground gutta percha particles dispersed within a polydimethylsiloxane matrix and contains platinum catalyst, zirconium dioxide as a radiopacifier, nanosilver, and bioactive glass particles. Compared with earlier formulations, GuttaFlow Bioseal includes bioactive glass to improve its biological performance. Studies have demonstrated that this material exhibits favorable physicochemical properties, including low

solubility, minimal porosity, alkalizing potential, good dentinal tubule penetration, and acceptable cytocompatibility. After contact with tissue fluids, calcium and silicate ions released from matrix which promote hydroxyapatite formation and biomineralization at the dentin–sealer interface, potentially improving the sealing ability and supporting periapical tissue healing. Nevertheless, evidence regarding its setting mechanism, long-term sealing performance, and retrievability during nonsurgical retreatment remains limited, and further investigations are required to validate its long-term clinical effectiveness [25].

GuttaFlow Bioseal was developed to combine the handling advantages of

silicone-based sealers with the bioactivity of calcium silicate and bioactive glass. Following setting, the material is capable of forming a hydroxyapatite (HAp) layer on its surface, which enhances adhesion to the dentinal wall and may support the regeneration of mineralized tissues. This bioactive behavior has traditionally been associated with materials such as mineral trioxide aggregate (MTA) and bioactive glass. However, unlike these materials, which are often characterized by prolonged setting times and more complex handling procedures, GuttaFlow Bioseal offers a simpler clinical application with a relatively short setting time of approximately 12–16 minutes. These properties make it a clinically convenient bioactive sealer while maintaining the potential to improve long-term sealing performance and periapical healing [9].

4.4. Silicone based sealers

RoekoSeal was the first launched to the market in 1999 (Coltene/Whaledent) and based on silicone material comprising polydimethyl siloxane and silicone oil. It was expected to expand during setting and this will enhance microleakage. Modification of RoekoSeal by adding fine gutta-percha particles have led to the development of GuttaFlow in 2003 and GuttaFlow 2 in 2012 (Coltene/Whaledent), GuttaFlow which have similar components to GuttaFlow but in different proportions and supplied in an automix syringe. Also a novel sealer called GuttaFlow bioseal which launched to the market in 2016 containing calcium silicate particles was launched with intent to stimulate the natural regeneration mechanism[29].

4.4.1 GuttaFlow 2 (Coltene/Whaledent)

GuttaFlow 2 is a novel material for root canal obturation introduced in 2012 which combines two products in one polydimethyl-siloxane sealer and gutta-percha in powder form with a particle size of less than 30µm with platinum catalyst,

zirconium dioxide and micro-silver. This sealer is considered to flow into the root canal system and fill the gaps between the canals and gutta-percha core due to its thixotropic phenomena after placement of the master cone. It doesn't shrink and claimed to have a good sealing ability due to its slightly expansion (0.2%) after setting. Additionally, Guttaflow is insoluble in tissue fluids. This results in a dimensionally stable and impervious root canal filling. Also it is a biocompatible material when compared with other sealers both in vitro and in vivo[30].

5. Obturation techniques:

Numerous obturation techniques are available for root canal treatment to achieve a three-dimensional root canal filling which is an important role in filling the morphologic irregularities within the root canal system and providing some degree of dentinal tubule sealer penetration for enhancing the obturation seal and preventing or minimizing microleakage[31]. Canal anatomy and the unique objectives of treatment in each case all of these are factors that affect on which technique the dentist will use. These techniques include lateral condensation, warm vertical condensation, the use of injectable thermoplasticized gutta-percha systems, carrier coated with an alpha phase gutta-percha, cold flowable obturation materials that combine gutta-percha and sealer in one product, single-cone obturation techniques and the embedded gutta-percha cones, all of which use gutta-percha as the core material and a flowable cement-like material as the sealer [32].

5.1 Single cone technique.

Several obturation systems and approaches have been developed in an effort to achieve a effective barrier against microbial penetration within the root canal

system. One major benefit of the single-cone technique is its simplicity [33].

Historically, the use of a single gutta-percha cone to obturate canals was not widely accepted because it relied heavily on the sealer to achieve adequate seal, which will get dissolution and shrinkage especially in ovoid canals. However, the use of single-point obturation has been returned with the advancement of the instrumentation techniques made it possible to prepare canals with larger tapers and accurately match the master gutta-percha cone to the size of the master apical file. Moreover, the new category of sealers which have the ability to be dimensional stable and doesn't affected by the dentinal and tissue fluid [34].

In single-cone obturation, the proportion of sealer is greater than that used in other techniques; consequently, the sealer's properties are of paramount important. A recent study has shown that the sealer properties are more important for elimination of microorganisms than the method of obturation[35].

The single-cone obturation technique offers several clinical advantages over conventional obturation methods. Unlike cold lateral condensation and warm vertical compaction, it does not require the placement of accessory gutta-percha cones or specialized compaction instruments. Following canal preparation with either stainless steel hand files or nickel–titanium (NiTi) rotary instruments, the root canal is thoroughly irrigated, disinfected, and dried. A master gutta-percha cone matched to the size and taper of the final shaping instrument is then coated with root canal sealer and inserted to the full working length. The sealer occupies the space between the gutta-percha cone and the canal walls, creating a homogeneous filling mass while minimizing voids and reducing the risk of procedural errors associated with the placement of multiple accessory cones. [36].

6. Critical analysis of current evidence:

Although bioceramic sealers have gained considerable attention because of their bioactivity and favorable physicochemical properties, the available literature demonstrates inconsistent findings regarding their sealing ability. For example, Ozasir[37] reported that AH plus exhibited the lowest apical and coronal microleakage among several sealers, whereas EndoSequence BC demonstrated the highest coronal leakage. Naji[38] found that AH Plus demonstrated higher apical seal than BC sealer. In contrast, Haridas et al. (2024), Lin et al. (2023), Zhang et al. (2025), and Wang et al. (2025) [39,40,41,42], reported superior adaptation, reduced void formation, and improved sealing performance for calcium silicate-based or bioceramic sealers compared with AH Plus. These contradictory findings suggest that the sealing performance of root canal sealers cannot be attributed solely to material composition. The differences in canal drying protocols may significantly influence BC sealer setting characteristics. Therefore, One possible explanation for these discrepancies is variation in moisture conditions during obturation. Bioceramic sealers depend on environmental moisture to initiate and complete their hydration reaction[43].

The obturation technique is another factor that may contribute to conflicting results. While several studies employed the single-cone technique with favorable outcomes for bioceramic sealers[40,41]. Akhtar et al. (2023) [44] reported that sealer type significantly affected apical sealing whereas the obturation technique itself did not significantly influence leakage values. Conversely, Zhang et al. (2025) [40] demonstrated differences between single-cone and warm vertical compaction approaches depending on the sealer used. These findings suggest that the interaction between sealer properties and obturation technique may be more important than the technique alone.

Differences in leakage assessment methods may also explain variations among studies. Dye penetration tests were employed

by Akhtar et al. (2023), Wang et al. (2025), and Zhang et al. (2025) [41,42,44], whereas Haridas et al. (2024) and Lin et al. (2023) [39,40] used micro-computed tomography, Ozasir et al. (2021)[37] used confocal laser scanning microscopy and Naji et al.(2020)[38] used Dye extraction method. Each technique evaluates different aspects of sealing performance and possesses inherent limitations. Dye penetration methods are inexpensive and widely used; however, they lack clinical relevance, do not accurately simulate bacterial leakage, and are difficult to standardize. Consequently, direct comparison among studies employing different assessment techniques should be interpreted with caution.

7. Conclusion:

Based on the available evidence, the sealing performance of root canal obturation is influenced by both the physicochemical properties of the sealer and the obturation technique employed. Although many studies reported favorable sealing performance for bioceramic sealers, the available evidence remains heterogeneous and no definitive superiority can currently be established. Bioceramic sealers generally enhance dentinal tubule penetration, improved adaptation to canal walls, and reduced microleakage compared with conventional resin-based sealers. Although warm obturation techniques may improve sealer distribution and adaptation, single-cone obturation combined with modern bioceramic sealers frequently produced comparable outcomes. Nevertheless, considerable methodological heterogeneity among the included studies limits direct comparison of results. Further well-designed studies using standardized evaluation methods are required to establish definitive clinical recommendations regarding the optimal sealer–obturation technique combination for achieving long-term root canal sealing.

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