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Endodontic Sealers: A Comprehensive Review

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ABSTRACT
Endodontic sealers are essential for achieving a hermetic seal in root canal therapy because they prevent bacterial microleakage and ensure long-term success. Here, the classifications, properties and advancements of the endodontic sealers shall be discussed together with their specific role in the obturation procedure of the roots. The other traditional sealers include zinc oxide-eugenol (ZOE) and its calcium hydroxide-based analogues, but these have failed to show resistance to solubility. Resin-based and bioceramic sealers have superior adhesion, dimensional stability, and bioactivity with promotion of hydroxyapatite formation for improved biocompatibility. Recent nanotechnology and bioactive material development have further improved sealing ability and tissue regeneration potential. The review also discusses the effect of the technique of sealer application such as lateral condensation, warm vertical compaction, and single-cone techniques on the outcome of treatment. Even with improvements, sealer extrusion, shrinkage, and retrieval difficulties are still challenges. Future trends include the incorporation of nanoparticles and improved bonding systems to enhance clinical performance. The characteristics and applications of various sealers must be understood to achieve predictable success in root canal treatment.

Keywords: Endodontic Sealers; Dental Materials; Root Canal Preparation; Biocompatible Materials; Endodontics

I. INTRODUCTION

In the traditional approach, the endodontic treatment is initiated by cleansing and shaping the root canal. The procedure further involves obturation to create an hermetic seal, which avoids the entry of bacteria and is required for the long-term success of the root canal therapy. The primary aim of obturation is to seal the canal from the coronal orifice to the apical foramen to protect the peri-radicular tissues from the byproducts of bacterial activity [1][2].

Endodontic sealers are essential to this process because they seal variations like tubules and lateral canals and fill in gaps that core materials like gutta-percha cannot. Additionally, one of the main causes of endodontic failure, microleakage, is prevented by these materials [3][4]. No sealer currently fulfills all ideal requirements, such as biocompatibility, antibacterial qualities, and dimensional stability, despite advances in material science [4].

Recent advancements in sealer compositions, particularly those incorporating bioactive substances such as tricalcium silicate-based sealers, have redirected attention towards improving both sealing efficiency and the regeneration of tissues. These bioactive sealers promote the formation of hydroxyapatite, which in turn improves biocompatibility and tissue integration, as stated by Komabayashi et al. [4][5]. Additionally, considering their exceptional compatibility with root canal walls and their potential for long-term effectiveness in therapeutic applications, bioceramic sealers have emerged as a significant advancement [6].

Sealers enhance the overall quality of the sealing, offer antibacterial qualities, and encase any remaining microorganisms in combination with core materials. Lentulo spirals and ultrasonic activation are two of their application methods that further maximize their effectiveness by guaranteeing sufficient penetration and coverage within the root canal system [7][8].Moreover, materials such as calcium hydroxide-based sealers are still widely used due to their ability to promote periapical healing, along with traditional zinc oxide-eugenol cements [9].

This review discusses the evolution, properties, and clinical applications of sealers,

emphasizing their indispensable role in achieving successful root canal therapy.

II. TYPES OF ENDODONTIC SEALERS.

1. Resin-Based Sealers

Resin-based sealers, such as AH Plus and AH26, are commonly used in endodontics because they have superior sealing qualities, greater adhesion to dentin, and less shrinkage than classic materials like zinc oxide-eugenol[8][10]. But they can cause transient inflammatory reactions when extruded into the periapical tissues, although the effects are usually resolved within a couple of weeks (Tomson et al., 2014) [7].

Methacrylate-based resin sealers, such as EndoREZ, present excellent flow and adhesion properties. These materials still require good handling to prevent oxygen inhibition in the bonding process because of their material characteristics that facilitate better penetration in dentinal tubules and accessory [5][11].

2. Zinc Oxide Eugenol (ZOE) Sealers

Zinc oxide eugenol-based sealers, such as Roth Root Canal Cement, have been in high usage in endodontics for a long time because of their good sealing properties and antimicrobial effects. However, their solubility and sluggish setting are limiting considerations, and they can induce transitory irritation in periapical tissues[9] [7] [10]. Increased solubility of ZOE sealers may damage long-term sealing performance, but their affordability and convenience of use remain advantages [5].

3. Sealers made of calcium hydroxide

Two popular calcium hydroxide-based sealers, Sealapex and Apexit, are prized for their capacity to encourage mineralization and have antibacterial qualities.Such sealers function by producing a very alkaline environment, which promotes tissue regeneration and eliminates any remaining germs [3] [12].

However, long-term sealing ability may be compromised due to their greater solubility [13]. Calcium hydroxide sealers are particularly useful in treating periapical inflammation and infections, and when used correctly, they stimulate osteogenesis[9] [12]. In addition, Vishwanath and Rao (2019) emphasize their biocompatibility, which is essential for successful outcomes, and their ability to stimulate periapical healing [14].

4. Bioceramic Sealers

Bioceramic sealers, such as BioRoot™ RCS and TotalFill BC Sealer, have been shown to promote hydroxyapatite production, tissue regeneration, and provide superior sealing qualities [5] [7] These materials generate a chemical link with dentin, which explains their long-term efficacy in root canal therapy [6]. These are also highly biocompatible and well-tolerated by periapical tissues [13].

5. Glass Ionomer Sealers

Ketac-Endo which is a glass ionomer sealer , forms a chemical link with dentin by reacting with hydroxyapatite and polyacrylic acid which thereby gives Strong adhesion and apical sealing [10].

They also release fluoride, which inhibits the secondary caries. However, due to their high solubility and difficulty in removal during retreatment, they are not widely used. The adhesion can also become inconsistent in the middle and apical thirds of the canal, which is also challenging [15].

III. PROPERTIES OF SEALERS

3.1. Biocompatibility

Bioceramic sealers are highly known for their excellent biocompatibility, thus promoting tissue healing and integration [6]. Calcium silicate-based sealers, such as MTA, induce healing while producing minimal adverse tissue reactions [10].ZOE sealers, while efficient, can occasionally cause tissue responses in hypersensitive people [15].Calcium hydroxide-based sealers, such as Sealapex, are highly remarkable in promoting mineralization and healing of periapical tissues, as demonstrated by Jacobsen et al [9].

3.2. Flowability

Effective flowability is a vital requirement for any endodontic sealer, in order that voids and lateral canals may be totally filled. Excellent flow properties by resin-based sealers, such as EndoREZ, can penetrate into the accessory canals and dentinal tubules more efficiently, and improve the quality of the seal and success of the root canal treatment [4].Hydrophilic materials exhibit lateral swelling and flowability like that observed with SmartSeal by Tomson et al. [7].

3.3. Radiopacity

Radiopacity is a crucial feature since it allows the sealant to be seen clearly during X-ray examinations. Sealants based on resin, such AH Plus, are easily recognized on radiographs since they adhere to ISO requirements for radiopacity as shown in figure 1. [3]. Furthermore, bioceramic

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sealants have enough radiopacity to determine filling quality [10].

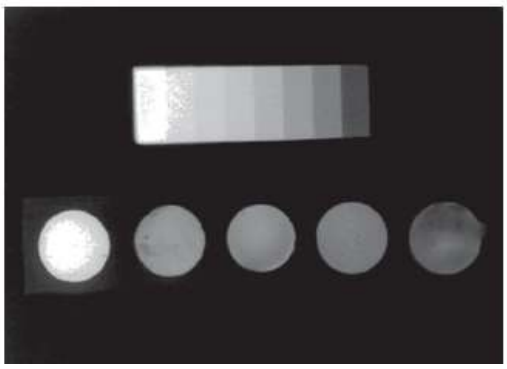

Fig. 1 – Radiograph showing the radiopacity of Sealer

3.4. Adhesion to Root Canal Walls

Bioceramic and resin-based sealers' adhesive qualities are crucial for minimizing microleakage and extending the durability of root canal therapy [4]. When compared to Sealapex or EndoREZ, Lin et al. claim that BioRoot RCS and EndoSeal MTA have better adherence to root dentin, even after artificial aging [5]. According to Kahn et al. [8], using EDTA as a final rinse increases the binding strength of compounds like Resilon.

3.5. Antibacterial Properties

Some sealers contain intrinsic antibacterial activity to improve treatment results. Calcium hydroxide-based sealers have high alkalinity that also helps antibacterial actions. Bioceramic sealers, with its sustained pH, also displays antimicrobial properties that help eliminate any remaining bacteria [2,4].

3.6. Dimensional Stability

Dimensional stability ensures that the sealers don't expand and contract over time and hence seal well. As compared to resin-based sealers, bio-ceramic sealers such as TotalFill BC Sealer are much more stable and minimize the occurrence of microleakage [4, 10].

3.7. Handling and Working Time

Optimal handling and adequate working time are provided for ease of application. For precise clinical procedures, resin-based sealers like AH Plus have a sufficient working time. Bioceramic sealers have good handling properties, especially in complex anatomy [7, 11].

IV. FUNCTION OF SEALERS IN ROOT CANAL TREATMENT

4.1. Sealing the Canal

Sealer fills up the spaces between the root canal walls and the obturating material, hence creating a hermetic seal that inhibits the bacterial re-entry and fluid leakage [10, 8]. This is important in order to avoid the re-infection, especially for complex root canal structures with collateral canals as stated by Kahn et al [8]. Leakage test by Jacobsen et al. It has been demonstrated that sealers such as calcium hydroxide-based materials act as an effective barrier against bacterial entry.[9]

4.2. Antibacterial Action

Certain sealants, for instance, calcium hydroxide-based sealants, and bioceramic sealants are bactericidal or antibacterial to help remove some residual bacteria within the root canal system [10, 7]. These attributes are essentials in blocking the formation of apical periodontitis as stated by Gatewood . [10].

4.3. Facilitating Dentin Bonding

Sealers used resins in gutta-percha enhance bonding, which helps strengthen the entire integrity of the obturation. Microleakage decreases and adhesion increases, enhancing the sealing capabilities of the system and therefore giving a long-term treatment success also [10, 7].

4.4. Sealing the Complex Anatomy

Sealers seal irregularities in the canal system, such as lateral canals and dentinal tubules. Sealers are used to fill these spaces, resulting in a more effective and tighter sealing process, especially in lateral condensation techniques [7]. All sealer types, including those with obturation, are more effective at sealing than untreated controls, according to Jacobsen et al. [9, 10]. As a result, they are essential for reaching 80% or higher adherence rates.

4.5. Lubrication and Material placement

In addition to sealing, the sealer acts as a lubricant when inserting gutta-percha or other filling materials, allowing for a good core fit and comprehensive coverage of the root canal space [7].As shown in Table 1, the functions of sealers and their associated benefits are outlined.

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Function	Material	Primary Benefit
Sealing the canal	Bioceramic, calcium hydroxide	Prevents bacterial re-entry and leakage
Antibacterial action	Calcium hydroxide, bioceramic	Eradicates residual bacteria
Facilitating dentin bonding	Resin-based sealers (ah plus)	Reduces microleakage, strengthens obturation
Sealing complex anatomy	Bioceramic, calcium hydroxide	Fills lateral canals, ensures tight obturation
Lubrication	All sealers	Facilitates seating of filling materials

Table 1: Functions of Sealers and Associated Benefits

REFERENCE FOR TABLE- [7-10]

V. TECHNIQUES FOR APPLYING ENDODONTIC SEALER

5.1. Commonly used techniques

Lateral Condensation: Gutta-percha is compressed laterally with a sealer to form an effective seal. Often combined with zinc oxide-eugenol sealers as shown in figure 2 [10].

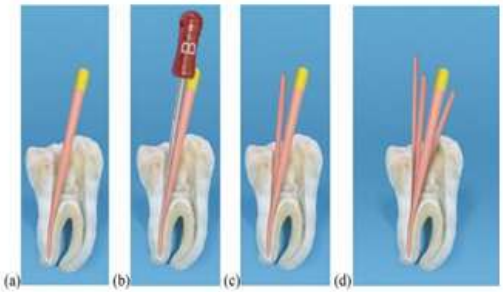

fig 2: Lateral Condensation Technique

Warm Vertical Compaction: Heat is applied to soften gutta-percha and promote better flow of the sealer to adapt well to the canal walls. It is most effective when used with resin-based sealers as shown in figure 3 [10].

Fig 3:Warm Vertical Compaction.

Single-Cone Technique: This is a less technique-sensitive method, where a single gutta-percha cone is combined with a sealer. It is highly suitable for resin-based sealers and bio-ceramic as shown in figure 4 [10].

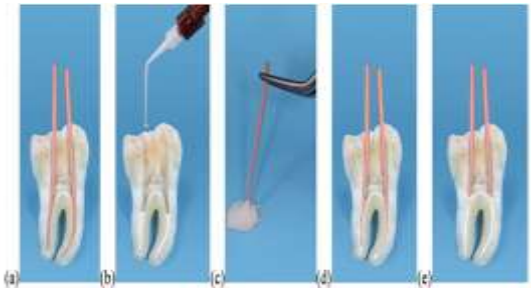

Fig 4-shows Single-Cone Technique in multiple canals.

5.2. Experimental Techniques

Kahn et al. (1997) compared six methods; they reported the lentulo spiral and Max-i-Probe Delivery System were most effective with regard to uniformity and complete sealer coverage. Ultrasonic and sonic files also performed well but not consistently [8].

Jacobsen et al. (1987) utilized lateral condensation in which the sealer was applied through paper points and the gutta-percha compacted using finger pluggers, hence achieving excellent fill with close adaptation to canal walls [9].

VI. CLINICAL PERFORMANCE OF DIFFERENT SEALING MATERIALS

6.1. Bioceramic Sealers

They are highly known for their biocompatibility and tissue regeneration properties. They form a tight seal and are also sensitive to the irregularities of the canal. According to researchers, these sealers are especially effective at reducing bacterial leakage [7, 10].

6.2. Resin-Based Sealers

The superior adhesion and sealing qualities of EndoREZ and other resin-based sealers are widely recognized. In one study, resin-based sealers in root canal therapy achieved a success rate of 91.03% after two years and 92.0% after five years, indicating excellent long-term clinical performance [11]. However, handling and manipulation issues can have an impact on the outcome in certain clinical scenarios [10].

6.3. Calcium Hydroxide-Based Sealers

According to Jacobsen et al. (1987), zinc oxide-eugenol cement and calcium hydroxide-based sealers (such as Sealapex) did not significantly differ in their ability to arrest leakage. In comparison to untreated controls, these materials

continued to be effective in preventing bacterial invasion despite some leakage [9].

6.4. Comparative Observations

Gatewood (2007) noted that the clinical performance of sealers is influenced by application techniques and material properties. Bioceramic and resin-based sealers generally outperform traditional materials in preventing reinfection and enhancing treatment outcomes [10].

VII. FACTORS AFFECTING EFFICACY OF SEALING MATERIALS

The success of sealers in root canal treatment depends on several important factors:

Canal Anatomy: Complex or curved root canals are challenging to achieve a perfect seal. High-flowability sealers, such as bioceramic formulations, are more appropriate for such cases because they adapt to the intricate canal system, thus ensuring a proper seal [10-11].

Type of Sealer: There are various types of sealers, and each has different advantages. Resin-based sealers bond well to canal walls but can have a problem with incomplete polymerization because of the oxygen-inhibited layer. Tomson et al. have focused on bioceramic sealers and Resilon for excellent sealing ability and biocompatibility, although bioceramics do have some solubility over time [7][10].

Material Properties: The solubility, adhesion to dentin, shrinkage during setting, and antimicrobial activity of sealers significantly impact their effectiveness. Bioceramic sealers stand out for their ability to release calcium ions, which aid in healing and mineralization. Resilon has also demonstrated superior properties in sealing and tissue compatibility [7][11].

Application Technique: The application method is very important for sealers' effectiveness. Techniques like warm vertical compaction or lateral compaction allow better distribution of the sealer. Kahn et al. (1997) have reported that though lentulo spiral has been very effective in providing equal distribution, the breakage occurring in curved canals is quite common, making it less effective in such a situation [8][10].

Instrumentation and Irrigation: Smear layer removal with the aid of EDTA significantly increases the adhesion of sealers to dentin. Lack of effective irrigation protocols leads to residual debris compromise of the seal [11].

VIII. CHALLENGES IN SELECTING SEALING MATERIALS

Biocompatibility: Certain materials, such as zinc oxide-eugenol-based sealers, can irritate the surrounding tissues, delaying healing. Similarly, unset resin-based sealers might exhibit cytotoxicity, though this risk decreases once they fully set [10][7].

Ease of Use: Resin-based sealers are very adhesive but not easy to handle in narrow or curved canals, thus creating a risk for application failure. Bioceramic sealers are simpler to use, but they are prone to overfilling if not applied with great care and precision [10][11].

Cost and Access: More expensive and less accessible for the general clinic, particularly in a low-resource setting, higher-quality sealers, such as bioceramic, may be less feasible to employ for some clinicians [7][10].

Operator Skills: The clinician's knowledge of specific materials and techniques is crucial to the success of the seal. In complex cases, such as curved canals, a combination of skill, experience, and the right materials are necessary to achieve optimal results [7].

IX. RECENT ADVANCES IN SEALERS

Sealer technology has advanced in recent years, with improved biocompatibility, sealing ability, and antimicrobial properties. Bioceramic sealers and calcium silicate-based sealers improve sealing properties and promote tissue regeneration [7-10].

Advances in bioceramic materials, including MTA-based sealers, have shown excellent results in forming a high-quality seal and encouraging periapical tissue healing [10]. New techniques, such as the use of harpooning catalyst-coated accessory cones after placing the master cone, have been developed to accelerate the setting reaction and minimize polymerization shrinkage, thereby improving the overall sealing ability of methacrylate-based resin sealers (MBRS) [11].

X. FUTURE TRENDS IN SEALER MATERIALS

At present, future sealers focus on further improving the material and techniques being used. Nanotechnology in sealers is considered to improve mechanical properties, antimicrobial activity, and overall performance. Bioactive materials for tissue regeneration receive much attention in research today[10].

In the category of clinical performance, this represents a step forward for innovation like harpooning of catalyst-coated accessory cones. It

minimizes the use of sealer in the first place while promoting the better polymerization needed for an excellent hermetic seal [7][11].

There is also a trend toward bonding systems in endodontics to create a continuous bond from the root canal to the coronal surface. The goal is to improve the durability and quality of obturation [11].

XI. COMPLICATIONS OF SEALERS

Despite advancements, certain complications still pose challenges in effectively using sealers:

Sealer Extrusion: If sealer is overfilled or misapplied, it may extrude into the periapical tissues, which may lead to inflammation or foreign body reactions. This is especially important when using lentulo spirals, which may break during application [8][10].

Shrinkage Upon Setting: Some resin-based sealers exhibit shrinkage as they polymerize, and the gaps formed are likely to contribute to microleakage. This remains a significant issue in ensuring long-term success [10].

Oxygen-Inhibited Layer: For MBRS, the oxygen-inhibited layer may impede proper polymerization, thus releasing unreacted monomers, which are toxic and likely to irritate tissues if not handled with caution [11].

Toxicity: Sealers like zinc oxide-eugenol cause irritation of the surrounding tissues because of its chemical composition. Though this may be temporary, it shows a requirement for biocompatibility improvement in materials used [10].

Sealers with decreased risk factors, enhancing their biological and physical properties, are the way to the future.

XII. RETRIEVAL OF SEALERS

The removal of sealers is essential in endodontic retreatment because it impacts the success of subsequent procedures significantly. The retrieval complexity depends on the sealer composition, adhesion to dentin, and the tools and techniques used.

Efficacy of Removal Techniques:

ZOE sealers have excellent adhesive properties and are quite difficult to remove at retreatment. Bioceramic sealers, though very adhesive to dentin, tend to be more retrievable using mechanical instruments, such as rotary files or ultrasonic devices [5][6]. Resin-based sealers, like EndoREZ, require heat-assisted techniques along with solvents such as chloroform or eucalyptol for effective removal [4][7]. It is therefore obvious that the sealer selected impacts the retrieval procedure.

Comparison of Sealer Types:

Bioceramic sealers have excellent sealing characteristics and are biocompatible but are more resistant to chemical dissolution compared to others [2][3]. Resin-based sealers possess good bonding characteristics but are quite adhesive, thus making retrieval hard [1][6]. A systematic review suggested that bioceramic sealers can be retrieved using appropriate techniques, although complete removal may not be feasible in most cases [1]. This implies that practitioners should be conscious of the shortcomings associated with each type of sealer in advance of retreatment planning.

To improve the effectiveness of sealer removal, heat-assisted techniques should be combined with rotary instrumentation and solvents such as EDTA. This can be beneficial for more successful retrievals [4][5]. The use of advanced visualization also increases the precision in the retrieval process, where practitioners can cause minimal damage to canal walls and adjacent tissues [3][6].

Depending on the type of sealer and the clinical situation, retrieval methods must be adjusted to optimize results.

In conclusion, while bioceramic sealers have potential due to their sealing properties, they present retrieval challenges. This emphasizes the need for ongoing innovation in retreatment techniques. To achieve effective results, clinicians should select appropriate methods based on the material and clinical situation [2][3][4][5][6]. This knowledge is critical for increasing success rates in endodontic treatments.

XIII. CONCLUSION AND RECOMMENDATIONS

Sealers are key in the successful long-term treatment of root canals by maintaining fluid-tight seals to prevent bacterial entry, bury residual bacteria, and facilitate periapical healing. Modern types include bioceramic and resin-based sealers, whose developments have exhibited important improvements both in sealing performance and biological aspects, but still, however, there is shrinkage and extrusion challenge [4][7][10].

Bioceramic sealers present the advantage of promoting hydroxyapatite formation and facilitating tissue regeneration, with a good fit for cases needing enhanced healing. They maintain elevated pH levels with time, that supports antimicrobial activity and mineralization, according to Poggio et al. [2][4].

Conversely, resin-based sealers offer superior bonding, but they must be placed carefully to prevent issues like polymerization shrinkage and cytotoxicity from unreacted monomers [7][11].

Key Recommendations for Clinical Practice:

- **Tailored Sealer Selection:** Clinicians should select sealers based on clinical requirements, considering factors such as canal anatomy, patient-specific needs, and the material's biocompatibility and sealing properties [4][7].
- **Optimized Application Techniques:** Use warm vertical compaction or lentulo spirals to improve sealer distribution and reduce microleakage [8][10].
- **Proper Irrigation Protocols:** Use EDTA to remove the smear layer, improve sealer adhesion, and reduce leakage risks [8][10].
- **Extrusion Risk Management:** Careful attention should be given to prevent overfilling and sealer extrusion. This is necessary to reduce periapical tissue irritation [7][11].
- **Focus on Material Advancements:** More emphasis should be placed on material advances such as nanotechnology and bioactive materials to further enhance biocompatibility, mechanical properties, and antimicrobial effects [2][10].

Evaluation of solubility, stability in pH, and adhesion will be important points for the long-term success of this material. Higher alkalinity combined with bioactivity makes bioceramic sealers highly promising for use in tissue repair and preventing microorganism accumulation [2][4][7].

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