Biomaterials Connect
ISSN: 3105-0387
2026, Article ID. 2026.0026, Cite as: https://doi.org/10.69709/BIOMATC.2026.130605

SCIFINITI PUBLISHING

Research Article

OPEN ACCESS

Morphological Studies of the Efficiency of Using Modern Endohermetics in the Treatment of Teeth with Destructive Periodontitis and Destroyed Apical Constriction

Vladimir Vasilyevich Glinkin[✉,1,*] **Victoria Vladimirovna Glinkina**[✉,2]

[1] Federal State Budgetary Educational Institution of Higher Education "Donetsk State Medical University Named after M. Gorky" of the Ministry of Health of the Russian Federation, Donetsk 83003, Russia
[2] State Budgetary Institution "Donetsk City Dental Clinic No. 1", Donetsk 83012, Russia

Article History
Received: June 05, 2025 Accepted: March 06, 2026 Published: May 20, 2026

Abstract

Introduction: Effective root canal obturation and the appropriate selection of sealer are the primary factors in preventing reinfection. A wide apical foramen, often resulting from inflammatory processes, can effectively preclude the possibility of achieving complete root canal sealing. **Objective:** To perform morphological studies of endodontic sealers used for filling canals of teeth with destructive forms of periodontitis and to assess the quality of root canal sealing in cases with destroyed apical constriction, using scanning electron microscopy (SEM). **Materials and methods:** Scanning electron microscopy (SEM) methods were used to study the morphology and microstructure of dental samples and filling materials. To assess the size of the apical foramen, we developed a method utilizing a gutta-percha point. Three materials were used as endosealers: Foredent, Sealapex, Trioxident. To manage patients with partially or severely compromised apical constrictions, a technique for orthograde root canal obturation using Trioxident cement was proposed and implemented in practice. Sections from the roots of 15 extracted teeth were prepared and categorized into three groups according to the type of endodontic sealer used. **Results:** The polymerization process of filling materials leads to shrinkage and the formation of micro cracks and micropores in them. Sealapex has an intermediate value of 7.32 μm ($p < 0.05$). The average sizes of the gaps between the endosealant and the tooth tissue in the area of the apical foramen were: Foredent 27.13 ± 3.58; Sealapex 66.81 ± 3.57; Trioxident 6.51 ± 3.55. **Conclusions:** The presence of microcracks and micropores in the studied materials can be explained by shrinkage during hardening. The average size of microcracks between the root canal wall and the endodontic filling material for Foredent was 16.9 μm, which is 15 times higher than the Trioxident values (1.11 μm). The hydration process inherent in Trioxident cement suggests that its application in orthograde root canal obturation may prevent resorption of the filling material in the apical portion of the tooth root and inhibit progression of pathological processes in the periodontium.

Keywords:
destructive periodontitis; apical constriction; endo-sealers; scanning electron microscopy; endohermetics

1. Introduction

To date, the frequency of patient visits for endodontic treatment has not declined. Periodontitis accounts for 50–80% of cases in which tooth extraction is indicated [1]. Patients with destructive forms of periodontitis constitute 30–45% of individuals seeking endodontic care, based on available data [2]. According to A. V. Durov (2018), these forms of periodontitis account for 20–56% of patients presenting for outpatient dental care [3].

* **Corresponding Author:**
Vladimir Vasilyevich Glinkin, Federal State Budgetary Educational Institution of Higher Education "Donetsk State Medical University Named after M. Gorky" of the Ministry of Health of the Russian Federation, Donetsk 83003, Russia, vvsyz1@gmail.com

© 2026 Copyright by the Authors.
Licensed as an open access article using a CC BY 4.0 license.

Successful endodontic treatment relies on three fundamental principles: thorough cleaning, effective disinfection, and complete obturation of the root canals [4,5]. Despite the importance of the first two components [6], root canal obturation remains equally essential [7]. I.A. Gor (2020) found in her research that in 22% of cases, the filling material is extruded beyond the root apex [8]. In this regard, improving the effectiveness of treatment of this group of teeth is a pressing issue in modern dentistry. D. Huang et al. (2024) argued that risk factors for endodontic treatment should be analyzed, as complications may occur in 57.8% of cases [9].

According to the quality indicators established by the European Society of Endodontology (ESE), the primary purpose of root canal obturation is to prevent the infiltration of microorganisms and fluids into the root canal system. To comply with the quality standards established by the European Society of Endodontology (ESE), it is essential to obturate not only the apical foramen but also the entire root canal system. Research by L. Z. Jovanović and B. V. Bajkin (2021) indicates that mineral trioxide aggregate (MTA) exhibits a satisfactory degree of marginal adaptation [10].

Analysis of previous studies indicates that high-quality root canal obturation and the appropriate selection of sealer are the primary factors in preventing reinfection [11,12]. This, in turn, enables a sustained therapeutic effect over the long term and, in many cases, facilitates the regeneration of periodontal tissues [13–15].

Today, the diagnosis dictates a treatment plan, the correct choice of which determines the regenerative processes in the periodontium [16]. Accurately determining the working length of the root canal has a significant impact on all stages and outcomes of periodontitis treatment [17]. In destructive forms of periodontitis, an enlarged apical foramen can preclude accurate determination of the canal's working length, and radiographic examination methods do not always permit detection of a compromised apical foramen [18]. In such cases, accurate determination of the root canal's working length cannot be guaranteed, and, consequently, the quality of instrumentation, medicament application, and canal obturation is also compromised.

Therefore, the high demand for endodontic care, the low success rate of treatment for teeth with compromised apical constrictions, and the absence of specific guidelines for the use of various root filling materials underscore the need to develop standardized methods for instrumentation and medicament application in root canals, as well as clear criteria for selecting appropriate root filling materials [19].

This study forms part of a comprehensive clinical and laboratory investigation that enabled analysis of endodontic sealers and supported the development of a differentiated approach to the treatment of teeth with periapical pathology.

2. Materials and Methods

Scanning electron microscopy (SEM) was employed to examine the morphology and microstructure of dental samples (extracted teeth) and root filling materials at the Department of Physics and Diagnostics of Advanced Materials, State Institution "Donetsk Physics and Technology Institute named after A. A. Galkin." The reliability and objectivity of the methods are ensured by the equipment: scanning electron microscope JSM-6490LV (JEOL, Japan) and energy-dispersive spectrometer INCA Penta FETx3 (Oxford, England), with the appropriate software and certified standard samples. The samples were examined using both SEI and BEI electronic signals. The standards used for quantitative analysis are certified and supplied by JEOL. Upon completion of the sample analysis, the resulting images were examined and processed using Microsoft Excel.

2.1. Verification of the Size of the Apical Foramen

To investigate the quality of root canal obturation in teeth with compromised apical constrictions, sections from 15 extracted tooth roots were prepared according to the method developed by [20] and subsequently divided into three groups based on the type of endodontic sealer employed. Endodontic treatment was performed on patients whose diagnosis corresponded to the ICD-10 codes: K04.5-K 04.8. Patient examination and treatment were conducted following written informed consent. The study adhered to the ethical principles of clinical research and the provisions of the Declaration of Helsinki of the World Medical Association, ensuring that patients' rights and health were fully protected. Before starting instrumental treatment of the root canal, its approximate working length was determined. Patients were categorized into three groups: those with preserved apical constriction, those with partially destroyed constriction, and those with severely destroyed constriction, according to the radiographic criteria established by M. Laux [21]. The teeth were also divided into three groups based on the endodontic sealant used: Foredent, Sealapex, Trioxident. In a retrospective cohort study of 156 patients, endodontic treatment was performed on 194 teeth (365 roots) with exacerbation of chronic forms of periodontitis, including those with destroyed apical constriction.

2026, Vol. 3, Article ID. 2026.0026
https://doi.org/10.69709/BIOMATC.2026.130605

Verification of the apical opening size can be performed using conical gutta-percha or a calcium-based temporary radiopaque filling material. For this purpose, we developed a method using a 25.06 gutta-percha pin. The gutta-percha pin was shortened by 1 mm using scissors until it reached a stop in the apical region. A calculation formula was subsequently developed and proposed to determine the diameter of the apical opening:

$$Ap_1 + K * L = Ap_2 \quad (1)$$

where Ap_1—is the initial size of gutta-percha (25 according to ISO); K—is the taper value of the gutta-percha pin (6); L—is the length by which the gutta-percha pin is shortened; Ap_2—is the final size of the gutta-percha. This formula enables the selection of an appropriate file for creating an apical stop in teeth with compromised apical constrictions.

For example, by reducing the pin size by 7 mm, using the formula, we get 67, which corresponds to the ISO file size of 65 or 0.65 mm: 25 + 6*7 = 67.

After establishing the apical stop with a calibrated gutta-percha pin, radiographic examination was performed. Following standardized chemomechanical treatment using a canal filler, the root canal was obturated along its entire working length with a calcium-containing temporary sealing material. In this case, no machine files were used more than 25.06 [22].

2.2. Protocol of Endodontic Preparation of Teeth for Root Canal Filling

The endodontic treatment protocol followed the standard approach [23] and included the following steps:

1. Mechanical treatment of the root canal to remove putrid masses and softened, infected dentin from the walls of the canal.
2. Medicinal treatment of the root canal to remove microflora and its toxins that caused the pathological process.
3. Obturation of the root canal to isolate periodontal tissues from microbial invasion.

2.3. Methodology of Endodontic Preparation of Tooth Samples In Vitro and Preparation of Tooth Sections for SEM Examination

Teeth were extracted if indicated, with the patient's informed consent. After extraction from the oral cavity, the teeth intended for examination were washed in distilled water and then immersed in it to minimize the possible impact of various factors on changes in the microelement composition of the tooth. For examination, the extracted teeth were positioned in a silicone mold fabricated from a C-silicone material, such as Zeta Plus, in accordance with the manufacturer's instructions.

After the silicone material had set, the teeth were prepared following the standard endodontic treatment protocol. According to the approved unified methodology, the procedure includes:

1. In order to create access to the root canals, the carious cavity is prepared.
2. Medicinal treatment of the carious cavity with antiseptic drugs.
3. Removal of putrid masses from the root canal system.
4. Mechanical expansion of the root canals to the entire working length using 4–6 taper files. The lumen of the canal is expanded to at least 25.04 according to ISO.
5. Antiseptic treatment of the root canals with 3 mL of 5.2% NaOCl solution and preparations containing EDTA, followed by drying the canals with paper points.
6. The root canals were filled according to the instructions for use of the specific material being studied.
7. The carious cavity was hermetically sealed using a cement, such as zinc phosphate cement "Unitsem".
8. After completing the work, remove the tooth from the silicone impression and moisten the inner surface of the impression with a physiological solution in order to simulate conditions close to physiological.
9. The material was allowed to harden in the root canals according to the time specified in the instructions. 10. A tooth section was then prepared according to the method described below.

2.4. Method of Preparing a Tooth Section (for SEM Examination)

1. Longitudinal or transverse sectioning of the extracted tooth root was performed using a diamond separating disk, taking care to avoid overheating and thereby prevent cracking of the specimen.
2. The resulting sample was embedded in epoxy resin (resin: hardener ratio 9:1). After its polymerization (at least 24 h), the surface of the section is polished.
3. Polishing the section:
   - 3.1. Grinding with sandpaper: in stages with roughness P100, P240, P500, P1000, P2000.
   - 3.2. Polishing: in stages with diamond pastes with grain size 10/7, 5/3, 1/0.

3.3. Polishing with a universal diamond suspension (DiaDuo-2, grain size 1.0 μm).
3.4. Finish polishing with a colloidal silicon suspension (OP-S, grain size 0.04 μm).

4. A conductive carbon layer was applied to the surface of the obtained section by spraying in a VUP-5A unit.
5. The sprayed section is fixed on the stage, ensuring reliable electrical contact between the surface of the section and the stage.
6. The stage with the fixed sample is placed in the microscope column for research.

2.5. Method of Preparation of a Sample of Filling Material (for SEM Examination)

1. The material intended for examination was mixed as for filling a prepared tooth canal, according to the instructions for the material being examined.
2. The resulting mixture or gutta-percha pin is applied to a double-sided carbon conductive tape, previously fixed to a substrate.
3. After complete hardening of the endo-sealant in air at t 22 °C, the substrate with the sample fixed to it is placed in a VUP-5A vacuum unit for applying a conductive coating.
4. The sprayed sample with the substrate is fixed on the stage, ensuring reliable electrical contact between the substrate and the stage.
5. The stage with the sample is placed in the microscope column for examination.

2.6. Characteristics of the Studied Endo-Sealants

The first group of root canals was filled with Foredent. This material by Spofa Dental is based on resorcinol-formaldehyde resin and is produced in the Czech Republic. It consists of a powder and two liquids. The powder contains zinc oxide, barium sulfate, paraformaldehyde; the first liquid contains glycerin, formaldehyde solutum, purified water; the second liquid contains glycerin, purified water, resorcinol oxide hydrochloride. The paste hardens due to the action of a catalyst—sulfuric acid.

For the treatment of these categories of teeth, endodontic sealers from three distinct groups were employed: Foredent, Sealapex, Trioxident.

1. "Foredent"—contains paraformaldehyde (19–24%), which is a strong antiseptic. This underlies its disinfectant properties; however, it also exhibits pronounced mutagenic, teratogenic, and toxic effects. Furthermore, it has been previously established that the introduction of this endodontic sealant into the periapical space typically triggers an inflammatory response, often resulting in severe post-obturation pain that can persist from several minutes to several days, and, in some cases, may lead to long-term progression of pathological changes in the periodontal tissues [24].
2. The second group of root canals was filled with "Sealapex", a material produced in the USA by Kerr Hawe. This material is used in combination with gutta-percha and silver pins. Its composition includes calcium and zinc oxides, zinc stearate, titanium dioxide, barium sulfate, and submicron silicone glass. It sets effectively in a moist environment.

Sealapex is a eugenol-free calcium hydroxide-based endodontic filling material. It hardens in a humid environment. Experimental studies on animal teeth demonstrated that Sealapex facilitated apical closure by promoting the deposition of secondary cement in cases where the root canal filling terminated 1 mm short of the radiographic apex. The positive aspect is that Sealapex does not cause severe inflammation in the periapical tissues. However, complications were observed in 57.2% of cases when Sealapex was extended beyond the root apex [25]. This material also exhibits several limitations. Sealapex achieves complete setting only after three days. More than 3% of its mass and liquid are lost within 24 h, and the material does not meet the requirements of ISO 6876-86 in these parameters. However, the material's antibacterial effect is transient and diminishes over time due to the influence of tissue fluids [26]. These findings are supported by the observations of S. V. Tarasenko et al. (2018), who investigated the antibacterial effects of calcium hydroxide–based filling materials [27]. Foredent was employed to obturate the root canals using a canal filler. Sealapex served as a sealer in combination with gutta-percha points, applied via the lateral condensation technique

3. "Trioxident" is a dental endodontic water-curing material produced by VladMiVa in powder form, used according to the instructions for use. This material belongs to the MTA group. The cement is composed of calcium oxide, which reacts with water to form calcium hydroxide, creating a highly alkaline environment (pH 12.8):3CaOSiO2 + nH2O = 2CaO-SiO2 2H2O + Ca (OH) 2 + (n − 3) H2O. The composition contains oxides of silicon, aluminum, and bismuth, with copper-calcium hydroxide included as a bacteriostatic additive. N. Greenwood (2017) claims that aluminum oxide, due to its strong crystal lattice, is chemically inert and insoluble [28]. As

2026, Vol. 3, Article ID. 2026.0026
https://doi.org/10.69709/BIOMATC.2026.130605

bioinert materials, aluminum oxide and zirconium dioxide elicit minimal tissue response in the surrounding area [29]. Despite the different particle sizes, cement grains fit quite tightly together in water. A large number of small crystals are combined into a homogeneous fine-pored structure, which determines the strength characteristics of the cement. Upon mixing the cement with water, a chemical reaction takes place, resulting in the formation of a gel as the hydration product. This reaction proceeds over an extended period, during which the cement's strength gradually increases. This process underlies one of the key properties of the endodontic sealer—its adhesive capability [30]. Historically, this material was primarily used for retrograde root canal obturation following root apex resection or in cases of an unformed apex.

2.7. Method of Orthograde Root Canal Filling with Trioxident

The first portion of Trioxident material was introduced into the canal using a machine canal filler, filling it to ½ the length, and condensing it using a condenser, brush, or plugger. The second portion of the material was used to obturate the canal up to the coronal portion, employing a canal filler and subsequent condensation. X-ray quality control of root canal filling was performed. A cotton pellet moistened with sterile water was placed at the coronal portion of the root canal for 24 hours, and the tooth cavity was hermetically sealed using a temporary filling material. During the next visit, the tooth cavity was filled with a permanent material [31].

Root canal obturation with other sealers in all patient groups was performed in accordance with the manufacturers' instructions. Post-treatment follow-up of patients was conducted following the guidelines of the European Society of Endodontology [32].

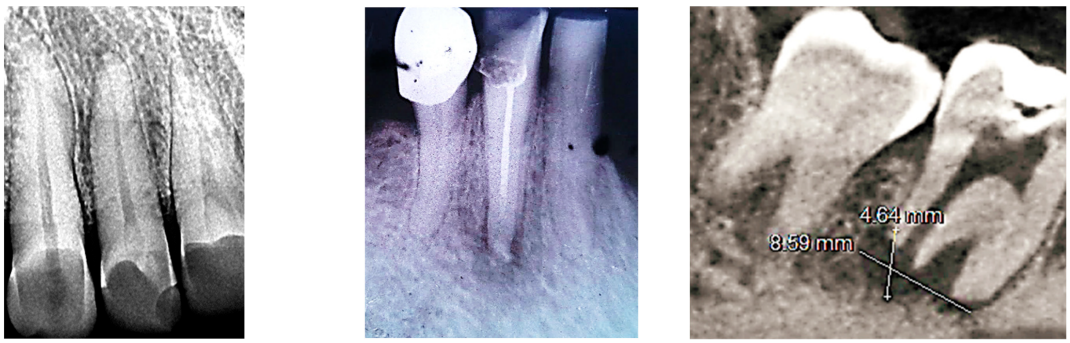
3. Results

In long-term inflammatory processes, the state of the apical constriction and the cemento-dentine border may change. Teeth with radiographically determined root resorption are particularly difficult to treat. In this regard, three categories of teeth were identified:

1. The category of teeth without signs of resorption.
2. The category of teeth with signs of moderate resorption, which was visualized on the X-ray as a blurry unevenness of the root contour.
3. Teeth with signs of severe resorption, visualized on radiographs as distinct radiolucent depressions or shortening of the root tip.

The size of the apical opening can be assessed in advance using the measurement scale of a radiovisiograph or a section of a computed tomography scan. Alternatively, a calcium hydroxide–based radiopaque temporary filling material may be employed. However, when using the tactile or periodontal sensitivity methods, inaccurate determination of the canal working length is possible.

The radiographic examination identified signs of root apex resorption in only 24% of the 194 treated teeth. Figure 1 shows X-ray images of three categories of teeth that meet the X-ray criteria of M. Laux.



(a) (b) (c)

Figure 1: Radiograph of tooth 12 without signs of resorption (**a**). Radiograph of tooth 42 with signs of moderate resorption (**b**). CBCT section of tooth 47 with signs of severe resorption (**c**).

To achieve more accurate measurements of the apical foramen in the absence of a radiovisiograph or CBCT, a method was proposed for calculating its size using a gutta-percha pin (Figure 2).

2026, Vol. 3, Article ID. 2026.0026
https://doi.org/10.69709/BIOMATC.2026.130605

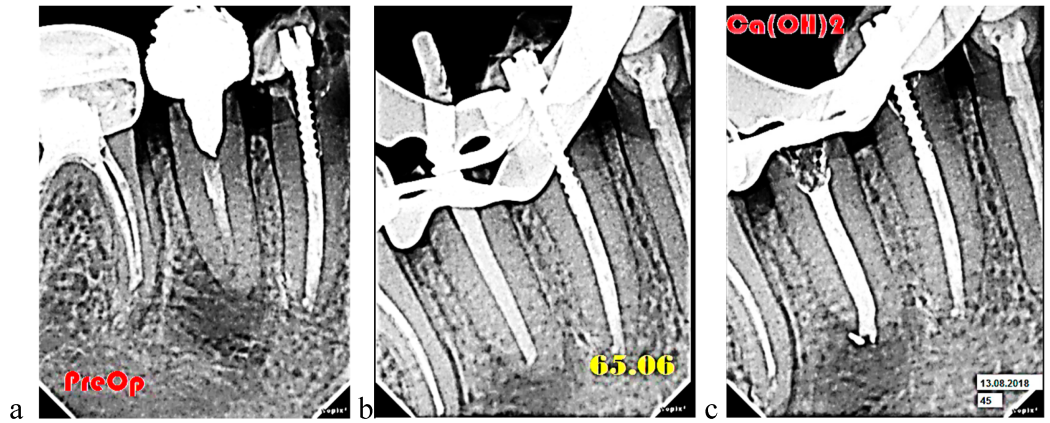


Figure 2: Example of determining the apical stop with a calibrated gutta-percha pin. Radiographs of tooth 45: initial situation (**a**); image with a calibrated gutta-percha pin of 06 taper (**b**); image with a temporary calcium-containing material in the root canal (**c**).

The morphological characteristics of the materials under study were analyzed using monochrome SEM images.

For standardization in this study, the particle size of the endodontic sealers under investigation was measured. Based on colloid chemistry classification, these materials can be categorized as medium-dispersed or finely dispersed systems (Figure 3).

According to the obtained SEM results (Figure 3a,b), it was established that Foredent, like the gutta-percha pin, is distinguished by the dispersion of particles (0.2–1.28 μm), with a predominance of medium-sized micro particles (0.4 ... 0.6 μm).

The gutta-percha pin (Figure 3b) is characterized by the presence of finely dispersed, uniformly distributed particles, 0.24–0.52 μm in size.

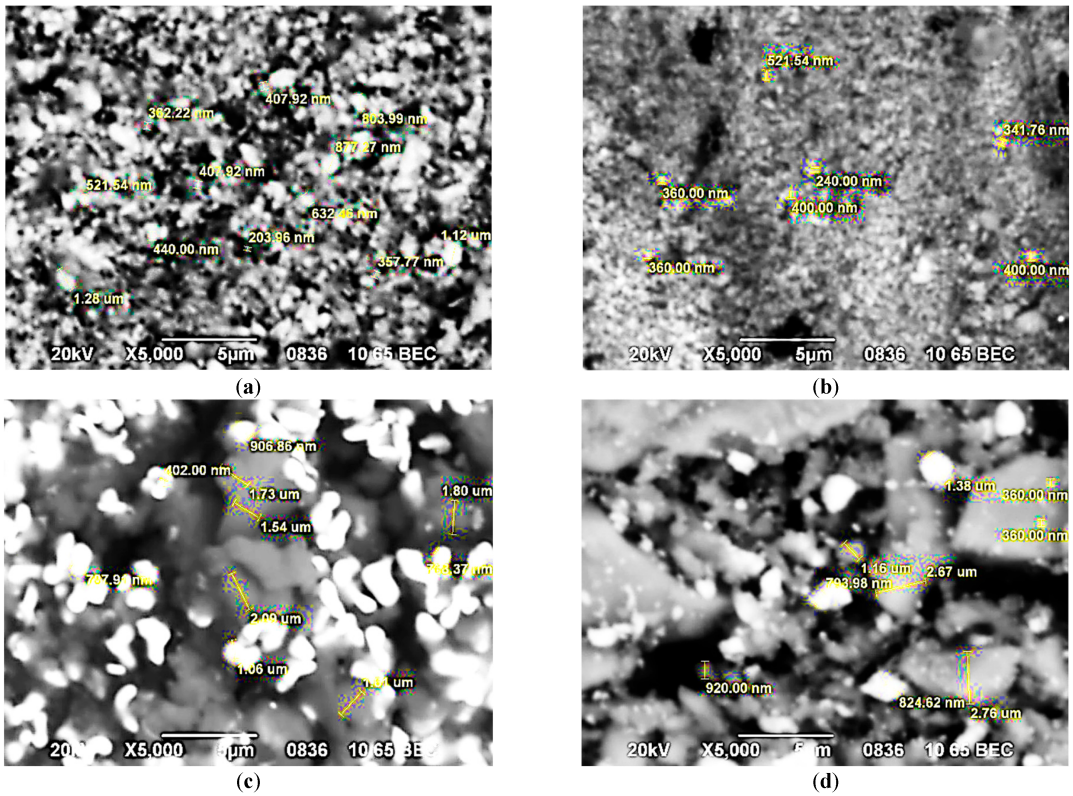


Figure 3: Morphology of filling materials with particle sizes indicated: Foredent (**a**), gutta-percha pin (**b**), Sealapex (**c**), Trioxident (**d**). SEM. BEC. Magnification 5000×.

2026, Vol. 3, Article ID. 2026.0026
https://doi.org/10.69709/BIOMATC.2026.130605

In Sealapex (Figure 3c), the presence of three types of particles was noted, which differ both in contrast and in composition. These are small light-grey particles containing zinc (<0.1 μm), bright-white particles of barium sulfate (0.4–1.0 μm), and large calcium-containing particles (1.06–2.09 μm) that form conglomerates up to 5 μm in size. In our opinion, this material can be classified as medium-dispersed by the size of its micro particles and classified as a very fine powder by the dispersion of its particles.

Although these endodontic sealers may be classified as homogeneous, close packing between their microparticles was not observed.

Trioxident (Figure 3d) is characterized by the presence of mainly two types of particles that differ in contrast and composition. These are bright white particles containing zirconium (from <0.1 to 1.38 μm) and large calcium- and calcium-silicon-containing particles (from 1.0 to 5.0 μm). The obtained data indicate that Trioxident is a heterogeneous material, as its particle sizes range from coarse (>30 μm) to finely dispersed (<1 μm). This material combines both (highly) colloidal-dispersed and coarsely dispersed particles and, in terms of particle dispersion, combines large particles and very fine powder. This combination of microparticles is believed to enhance the material's strength characteristics. Additionally, analysis of Trioxident revealed a hydration process accompanied by the formation of crystalline hydrates (Figure 4).

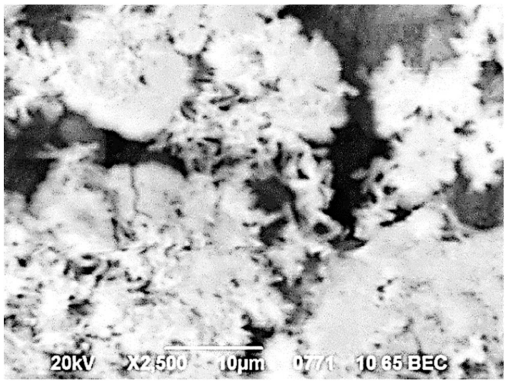


Figure 4: The process of hydration with the formation of crystal hydrates in Trioxident in the apical part of the root canal. SEM. VES. Magnification: ×2500.

Scanning electron microscopy (SEM) analysis revealed that the hydration process begins within the first few days after filling and persists over an extended period, contributing to an increase in the material's strength characteristics. In the experimental samples, an increase in the surface area of the solid phase of the cement gel was also observed. Over time, the gel pores are filled with a fine-porous structure. A humid environment in the periapical space helps preserve moisture within the filling material, thereby contributing to its strengthening.

A humid environment in the periapical space maintains moisture within the filling material, thereby enhancing its strength.

In Foredent, short but rather wide micro cracks (~16.9 μm) were found throughout the entire length, combined with a fairly significant number of small micropores measuring ~0.87 μm, located at the border of large and small micro particles. In our opinion, this may be the result of shrinkage during material curing, since the Foredent polymerization process leads to the formation of micro cracks and micropores due to micro stresses.

Gutta-percha exhibits a homogeneous, finely dispersed structure with isolated small pores.

Sealapex is a material of uniform consistency, containing a minimal number of microcracks (~7.32 μm) and a relatively high content of micropores (~0.86 μm). It was observed that the micropores in the first two sealers are approximately the same size.

Due to the presence of microparticles of varying sizes, the particles in Trioxident do not fit tightly together, resulting in isolated microcracks (~1.11 μm) and micropores (~1.31 μm). At first glance, these features could be mistaken for larger micropores; however, the spaces between the microparticles are filled with a gel-like matrix. Unlike the previous materials, these were not voids. Therefore, in the case of Trioxident, the presence of micropores within the material's structure cannot be asserted. Small crystals are integrated into a finely porous, homogeneous structure, which governs the material's strength characteristics. During the study, it was noted that in Foredent and Sealapex, the micropores are almost the same size, as shown in Figure 5.

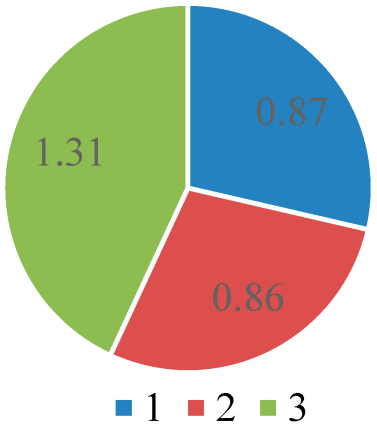
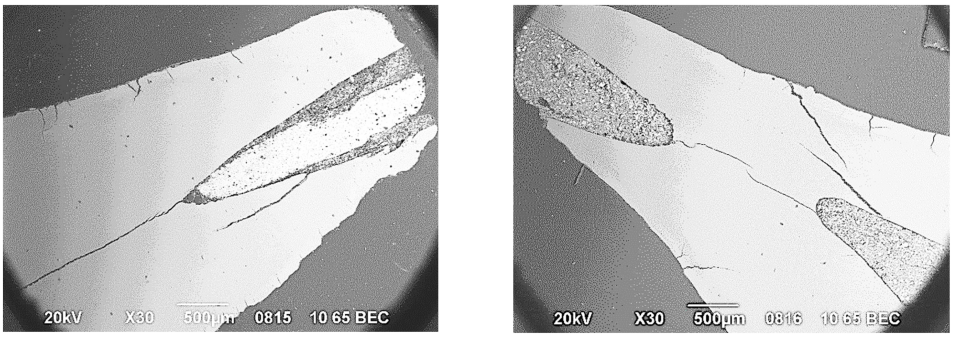


Figure 5: Average micropore sizes and distances between micro particles in the filling materials under study (in micrometers). Note: 1—Foredent; 2—Sealapex; 3—Trioxident.

The average size of micro-gaps was 16.9 μm for Foredent, which was approximately 15-fold greater than that for Trioxident (1.11 μm). When Trioxident was used, microgaps were observed only in the middle third of the canal. In our opinion, this is due to poor penetration of liquid into this section of the root canal. Sealapex showed an intermediate microgap value of 7.32 μm ($p < 0.05$).

In addition to studying the structure of endodontic materials, their dispersion, homogeneity, and composition, the density of the material's adhesion to the canal walls after filling and complete hardening of the material was analyzed.

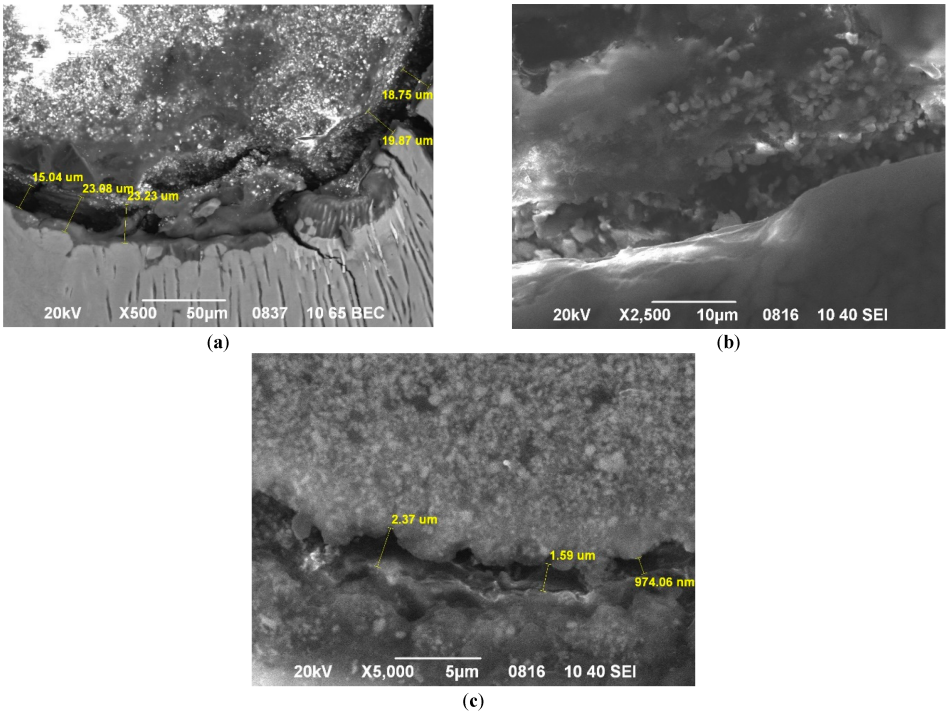
On sections of teeth filled with the materials under study, it is impossible to assess the quality of the filling at low magnifications. A tight adaptation of the endodontic sealer to the walls of the apical opening was consistently observed (Figure 6a,b).



(a) (b)

Figure 6: Adjacency of the studied filling materials in the apical region of the root canal: Sealapex with a gutta-percha pin (**a**), Trioxident (**b**). SEM. Contrast in BEC electrons. Magnification: ×30.

At higher magnification, a different pattern of sealer adaptation was observed across all samples. This is illustrated in Figure 7a–c, where microgaps between the canal wall and the endodontic material are clearly visible.



(a) (b) (c)

Figure 7: Micro gap between the canal wall and the filling material under study: Foredent (**a**), Sealapex (**b**), Trioxident (**c**). SEM. Contrast in BEC (**a**) and SEI electrons (**b**,**c**). Magnification: ×1000 (**a**), ×2500 (**b**), ×5000 (**c**).

2026, Vol. 3, Article ID. 2026.0026
https://doi.org/10.69709/BIOMATC.2026.130605

During the examination of the sections, it was observed that the poorest adaptation to the canal wall was observed with Foredent. Micro cracks are located in different places along the entire length of the root canal. In the root canals of the teeth filled with this material, the largest number of micropores and micro cracks were found both in the thickness of the filling material and in the parietal area of ~16.9 μm. At the same time, the size of the distance between the root canal wall and the filling material was ~6.99–26.22 μm.

When using Sealapex with gutta-percha pins, in 80% of the cases of the studied roots, micro cracks between dentin and sealer were found in the root canals in a limited number, measuring approximately 7.17–14.07 μm. In the middle third of the roots and in regions closer to the apex, a tight adaptation of the filling material to the canal walls was observed along the entire length. However, in areas with wide apical openings, this adaptation was found to be loose. In addition, tight adhesion between gutta-percha pins and sealer was noted along the entire length.

In root canals filled with Trioxident, loose fit to the canal wall was noted in 1–2 places in 40% of roots over a short length and small width (~0.84–1.63 μm) in the middle third of the root canals. This may be attributed to an insufficient amount of liquid required to strengthen the material in this region (Figure 8).

In vitro studies of teeth with destroyed apical constriction, sealed with Foredent and Sealapex, demonstrated leakage of the endosealant from the apical foramen in all cases (Figures 9 and 10). It was noted that Sealapex and Foredent formed a bulge when leaking, rising above the anatomical root apex with a loose fit to the root tissues. The gutta-percha pin extended beyond the apical foramen.

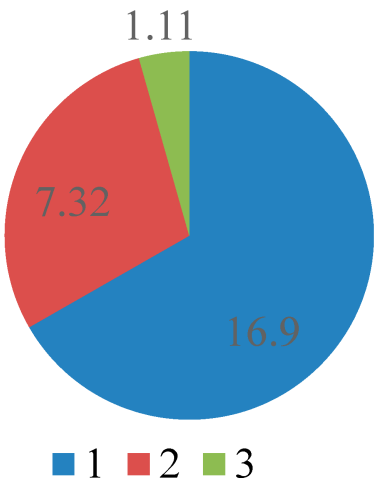
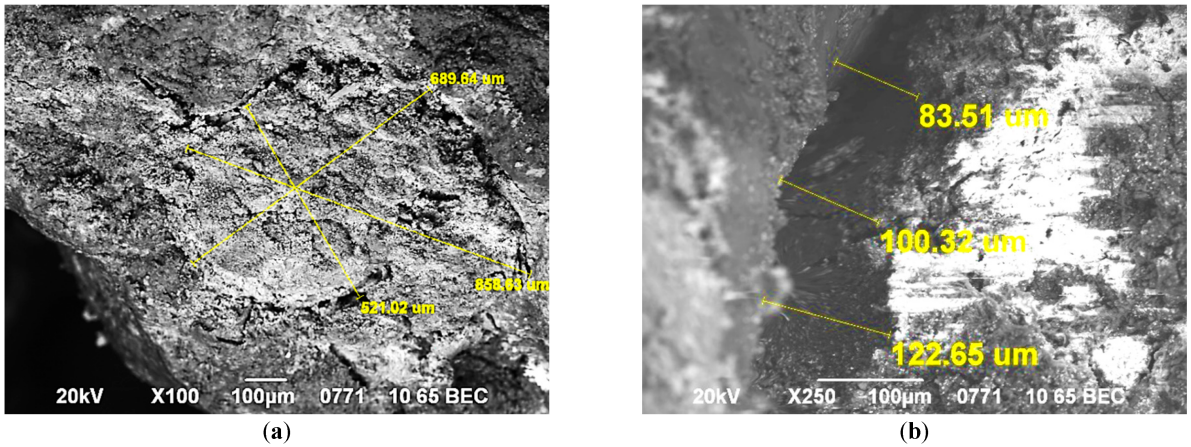


Figure 8: Average sizes of microcracks along the border of filling materials and root canal walls (in micrometers). Note: 1—Foredent; 2—Sealapex; 3—Trioxident.

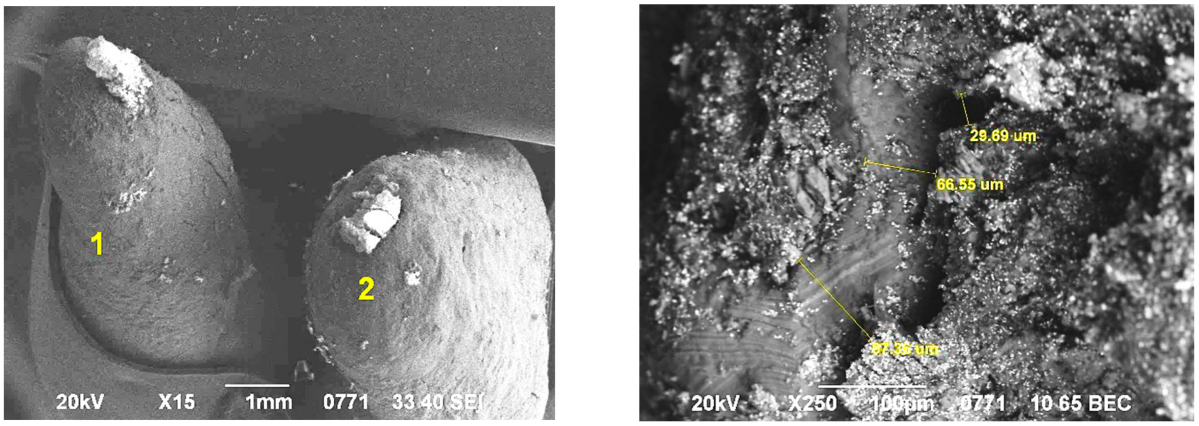
When Trioxident was used, material leakage was observed in 40% of cases, even when there was a tight adaptation of the material to the anatomical root apex (Figure 11). The average sizes of the gaps between the endosealant and the tooth tissue in the area of the apical foramen were: Foredent 27.13 ± 3.58; Sealapex 66.81 ± 3.57; Trioxident 6.51 ± 3.55.

The experiment cannot be considered fully controlled, as it is impossible to replicate all anatomical and physiological conditions during in vitro filling. Considering that all studies were conducted under equal conditions, it is possible to compare the effectiveness of canal obturation with different materials in teeth with destroyed apical constriction.



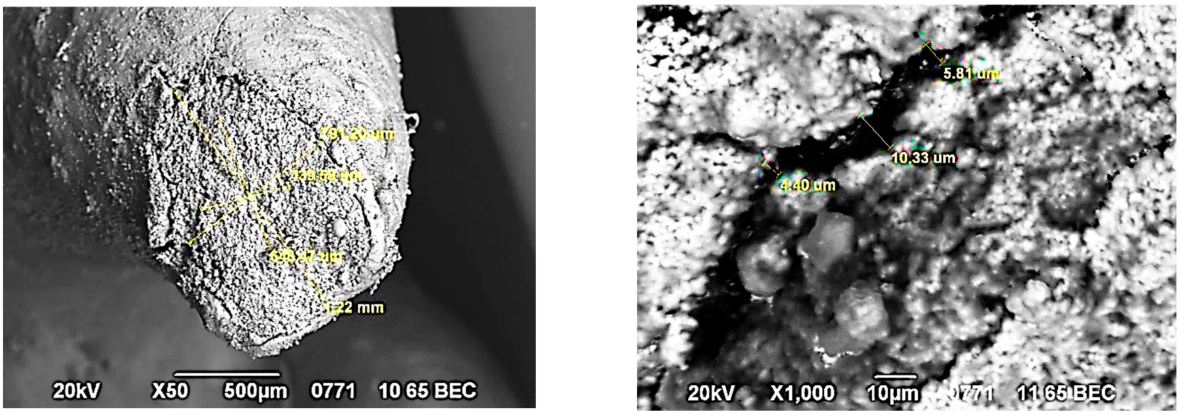
(**a**) (**b**)

Figure 9: View of the apical part of the root after filling (**a**). Micro gap between the canal wall and the Foredent filling material on the outer surface of the root (**b**). SEM. VES. Magnification: ×100 (**a**), 250 (**b**).



(a) (b)

Figure 10: View of the apical part of the root after filling (**a**). Micro gap between the canal wall and the filling material Sealapex with gutta-percha pins on the outer surface of the root (**b**). SEM. SEI and BEC. Magnification: ×15 (**a**), ×250 (**b**).



(a) (b)

Figure 11: View of the apical part of the root after filling (**a**). Micro gap between the canal wall and the Trioxident filling material on the outer surface of the root (**b**). SEM. VES. Magnification: ×50 (**a**), ×1000 (**b**).

4. Discussion

Data on the results of conservative treatment of teeth with destroyed apical constriction are ambiguous. Endodontic treatment currently addresses complex clinical challenges. For this purpose, we have developed and implemented a practical method for verifying the size of the apical opening. These measurements enable the clinician to accurately assess the apical opening, thereby informing the appropriate selection of an endodontic sealant. A critical factor in the success of endodontic treatment is the high-quality, permanent filling of root canals using appropriate endodontic sealers. Endodontic treatment failures are often linked to the quality of root canal filling, particularly in cases where the filling deviates from standard treatment protocols or is influenced by other therapeutic factors. Therefore, the selection of root filling material should be approached selectively, based on the specific clinical situation.

Before initiating treatment of teeth with apical forms of periodontitis, the clinician must have a clear understanding of the extent of apical constriction destruction to guide the selection of the most effective endodontic sealer for each specific case.

A comparative analysis of the most commonly used endo-sealers in dental practice, belonging to different groups, conducted using SEM, allowed us to propose their optimal use in filling teeth depending on the state of the apical constriction.

Depending on the condition of the apical opening, teeth with destructive apical periodontitis can be classified into three groups. For teeth with intact or partially destroyed apical constriction, the use of Sealapex with gutta-percha points (or similar calcium hydroxide–based materials) is recommended, as it exhibits an osteoinduc-

2026, Vol. 3, Article ID. 2026.0026
https://doi.org/10.69709/BIOMATC.2026.130605

tive effect that promotes lesion healing. For teeth with severely destroyed apical constriction, it is recommended to fill the root canals using Trioxident (or other MTA-based cements) via the orthograde technique. This approach enables high-quality obturation in a moist environment, forming a monoblock that adheres firmly to the root canal walls. The use of Trioxident is not recommended for filling teeth with intact apical constriction due to the high risk of seal failure in the absence of moisture within the root canal, as well as the practical difficulties associated with its application in such cases.

The presence of micropores in endodontic sealers, along with cracks or poor adaptation of the material to the root canal walls, suggests that these factors may contribute to long-term reinfection of the root canal.

5. Conclusions

Optimization of root canal obturation depends on the appropriate choice of endodontic sealer for teeth with different states of apical constriction. The presence of microdefects in these materials can compromise sealing effectiveness and increase permeability to both microorganisms and their toxins.

The presence of microcracks and micropores in the studied materials can be explained by shrinkage during hardening. The average size of microcracks between the root canal wall and the endodontic filling material for Foredent was 16.9 μm, which is 15 times higher than the Trioxident values (1.11 μm). Sealapex has an intermediate value of 7.32 μm ($p < 0.05$).

The orthograde method of filling root canals with Trioxident in cases of destroyed apical constriction has demonstrated high efficacy, attributable to cement hydration and strong marginal adhesion. We anticipate that this approach will prevent resorption of the filling material in the apical portion of the tooth root and inhibit the progression of pathological processes in the periodontium.

Taking into account the studies conducted using SEM, it is possible that the presence of an endo-sealer extended beyond the apex of the root canal on the radiograph does not necessarily mean tight obturation of the apical opening. In this context, the interaction between the endodontic sealant and the surrounding tissues becomes particularly significant.

Based on the condition of the apical opening, teeth with destructive apical periodontitis are recommended to be classified into three groups. For teeth with preserved and partially destroyed apical constriction, it is recommended to use Sealapex with gutta-percha pins. For a group of teeth with severely destroyed constriction, it is recommended to fill the root canals with Trioxident using the typical method. This technique enables high-quality obturation in a moist environment, forming a monoblock that adheres firmly to the root canal walls. However, the use of Trioxident is not recommended for teeth with intact apical constriction due to the high risk of seal failure in the absence of canal moisture and the technical difficulties associated with its placement in such cases.

This study helps the practitioner choose a specific endo-sealant when treating teeth with periapical pathology, based on knowledge of the degree of destruction of the apical constriction and the morphology of endo-sealants. Further clinical studies, validated through statistical analysis, will enhance the predictability of the treatment process.

List of Abbreviations

CBCT	Cone-Beam Computed Tomography
ESE	European Society of Endodontics
MTA	Mineral Trioxide Aggregate
SEM	Scanning Electron Microscopy

Author Contributions

Conceptualization, research, software development, writing—review and editing, visualization: V.V.G. (Vladimir Vasilyevich Glinkin); Research, data processing, writing—original draft preparation: V.V.G. (Victoria Vladimirovna Glinkina). All authors have read and agreed to the published version of the manuscript.

Availability of Data and Materials

All available data are presented in the study in the Results section of the manuscript.

Consent for Publication

No consent for publication is required, as the manuscript does not involve any individual personal data, images, videos, or other materials that would necessitate consent.

Ethics Approval and Consent to Participate

The study was conducted in accordance with the Declaration of Helsinki and received ethical approval from the Bioethics Commission of the Federal State Budgetary Educational Institution of Higher Education “Donetsk State Medical University named after M. Gorky” of the Ministry of Health of the Russian Federation (FSBEI VO DonSMU of the Ministry of Health of the Russian Federation) No. 1/5-1 dated 08.02.2024.

Human Rights

The study complies with the ethical principles of clinical trials and the provisions of the Declaration of Helsinki of the World Medical Association and completely excludes any infringement of the patients' interests or harm to their health.

Conflicts of Interest

The authors declare no conflicts of interest.

Funding

The study did not receive any external funding and was conducted using only institutional resources.

Acknowledgments

The authors express their sincere gratitude to V.V. Burkhovetsky, an employee of the Department of Physics and Diagnostics of Advanced Materials of the State Institution "Donetsk Physics and Technology Institute named after A.A. Galkin", for scientific research assistance and support in carrying out the research.

AI Declaration

The authors confirm that no AI tools were used to generate any content of this manuscript.

References

[1] Mitronin, A.V. Endodontic Treatment of Pulp and Periodontal Diseases. Part 1. Aspects of the Use of Antibacterial Drugs. *Endodontiya Today* **2012**, *10*, 9–15. [View Online]

[2] Rozenbaum, A.Y. Optimization of Complex Treatment of Patients with Chronic Apical Periodontitis. Doctoral Thesis, Sam. State Medical University, Samara, Russia, 2016. Available online: https://viewer.rusneb.ru/ru/000199_000009_006654504?page=1&rotate=0&theme=white (accessed on 21 April 2026).

[3] Durova, A.V. Conservative Treatment of Patients with Destructive Forms of Apical Periodontitis with Calcium Orthophosphate-Based Materials. Doctoral Thesis, Tver State Medical University, Tver', Russia, 2018. Available online: https://www.dissercat.com/content/konservativnoe-lechenie-patsientov-s-destruktivnymi-formami-apikalnykh-periodontitov-materia (accessed on 21 April 2026).

[4] Li, G.H.; Niu, L.N.; Selem, L.C.; Eid, A.A.; Bergeron, B.E.; Chen, J.-H.; Pashley, D.H.; Tay, F.R. Quality of Obturation Achieved by an Endodontic Core-Carrier System with Crosslinked Gutta-Percha Carrier in Single-Rooted Canals. *J. Dent.* **2014**, *42*, 1124–1134. [CrossRef] [PubMed]

[5] Jovanović, L.Z.; Bajkin, B.V. Scanning Electron Microscopy Analysis of Marginal Adaptation of Mineral Trioxide Aggregate, Tricalcium Silicate Cement, and Dental Amalgam as a Root End Filling Material. *Microsc. Res. Tech* **2021**, *84*, 2068–2074. [CrossRef] [PubMed]

[6] Haapasalo, M.; Endal, U.; Zandi, H.; Coil, J. Eradication of Endodontic Infection by Instrumentation and Irrigation Solutions. *Endod. Top.* **2005**, *10*, 77–102. [CrossRef]

[7] Gillen, B.M.; Looney, S.W.; Gu, L.S.; Loushine, B.A.; Weller, R.N.; Loushine, R.J.; Pashley, D.H.; Tay, F.R. Impact of the Quality of Coronal Restoration Versus the Quality of Root Canal Fillings on Success of Root Canal Treatment: A Systematic Review and Meta-Analysis. *J. Endod.* **2011**, *37*, 895–902. [CrossRef]

[8] Gor, I.A. Treatment of Patients with a Foreign Body (Filling Material) in the Bone Tissue of the Jaws and Soft Tissues. Doctoral Thesis, First Moscow State Medical University Named after I. M. Sechenov (Sechenov University), Moscow, Russia, 2020; 150p. Available online: https://www.sechenov.ru/upload/iblock/852/Gor-I.A.-dissertatsiya.pdf?ysclid=mo8kdeikvk396490753 (accessed on 21 April 2026).

[9] Huang, D.; Wang, X.; Liang, J.; Ling, J.; Bian, Z.; Yu, Q.; Hou, B.; Chen, X.; Li, J.; Ye, L.; et al. Expert Consensus on Difficulty Assessment of Endodontic Therapy. *Int. J. Oral. Sci.* **2024**, *16*, 1–11. [CrossRef]

[10] Amjroso-Silva, P.; Brasil, S.C.; Peres, A.R.; Tolentino, E.S.; Alves, F.R.; Siqueira, J.F., Jr.; Rôças, I.N. Influence of Sealer Type on Treatment Outcome of Teeth with Apical Periodontitis: A Systematic Review. *Braz. Dent. J.* **2023**, *34*, 1–21. [CrossRef]

[11] Silva, E.J.; de Lima, C.O.; Barbosa, A.F.; Ferreira, C.M.; Crozeta, B.M.; Lopes, R.T. Efficacy of an Arrow-Shaped Ultrasonic Tip for the Removal of Residual Root Canal Filling Materials. *Aust. Endod. J.* **2021**, *47*, 467–473. [CrossRef] [PubMed]

[12] Ricucci, D.; Lin, L.M.; Spångberg, L.S. Wound Healing of Apical Tissues after Root Canal Therapy: A Long-Term Clinical, Radiographic, and Histopathologic Observation Study. *Oral. Surg. Oral. Med. Oral. Pathol. Oral. Radiol. Endod.* **2009**, *108*, 609–621. [CrossRef] [PubMed]

[13] Glinkin, V. V. Comparative Analysis of Endosealants and Differentiated Approach to the Treatment of Teeth with Periapical Pathology: Clinical and Laboratory Study. Doctoral Thesis, Donetsk State Medical University, Donetsk, Ukraine, 2025; 24p. [View Online]

[14] Estrela, C.; Holland, R.; Estrela, C.R.; Alencar, A.H.G.; Sousa-Neto, M.D.; Pécora, J.D. Characterization of Successful Root Canal Treatment. *Braz. Dent. J.* **2014**, *25*, 3–11. [CrossRef]

[15] Li, G.H.; Niu, L.N.; Zhang, W.; Olsen, M.; De-Deus, G.; Eid, A.A.; Chen, J.-H.; Pashley, D.H.; Tay, F.R. Ability of New Obturation Materials to Improve the Seal of the Root Canal System: A Review. *Acta Biomater.* **2014**, *10*, 1050–1063. [CrossRef] [PubMed]

[16] Dash, G.; Mishra, L.; Singh, N.R.; Behera, R.; Misra, S.R.; Kumar, M.; Sokolowski, K.; Agarwal, K.; Behera, S.K.; Mishra, S.; et al. Prevalence and Quality of Endodontic Treatment in Patients with Cardiovascular Disease and Associated Risk Factors. *J. Clin. Med.* **2022**, *11*, 6046. [CrossRef] [PubMed]

[17] Gerasimova, L.P.; Aletdinova, S.M. Diagnosis and Comprehensive Treatment of Acute Chronic Apical Periodontitis. *Endodontiya Today* **2014**, *1*, 6–9. [View Online]

[18] Antanyan, A.A. *Effective Endodontics*, 2nd ed.; Medical Information Agency Publishing House LLC: Moscow, Russia, 2017; 232p. Available online: https://medkniga.ru/files/book_fragments_files/block-Antanyan.pdf. (In Russian)

[19] Hidoussi, E.; Al-Hawwaz, Z.M.; Zokkar, N.; Douki, N. Healing of Periapical Lesion after Root Canal Treatment: A Case Report. *Indian J. Conserv. Endod.* **2021**, *6*, 228–232. [CrossRef]

[20] Glinkin, V.V. Method of Endodontic Preparation of In-Vitro Samples and Preparation of Tooth Sections for Scanning Electron Microscope Research. Utility Model Patent No. 146473, 24 February 2021. Bulletin No. 8. Available online: http://journal.dnmu.ru/index.php/UC/article/download/650/432/ (accessed on 21 April 2026). (In Ukrainian)

[21] Laux, M.; Abbott, P.V.; Pajarola, G.; Nair, P.N. Apical Inflammatory Root Resorption: A Correlative Radiographic and Histological Assessment. *Int. Endod. J.* **2000**, *33*, 483–493. [CrossRef]

[22] Glinkin, V.V. Identifier of Electronic Document: CR0124260321; Verification of the Size of the Apical Opening by Calibration of a Gutta-Percha Pin to Determine the Degree of Destruction of the Apical Constriction. Available online: https://sis.nipo.gov.ua/en/search/detail/1633501/ (accessed on 21 April 2026). (In Russian)

[23] Gutman, J.L. *Problem Solving in Endodontics: Prevention, Diagnostics and Treatment*; Gutman, J.L.; Dumsha, T.S.; Lovell, P.E., Translators; MEDpress-inform: Moscow, Russia, 2008; 592p. Available online: https://dentald.ru/d/resheniye_problem_v_endodontii_gutman_2_izdaniye_2014.pdf.

[24] Tarasenko, S.V.; Gor, I.A. *The Role of the Removed Filling Material for Root Canals in the Development of Inflammation. Aktual'nye Voprosy Stomatologii: Sbornik Tezisov Mezhvuzovskoj Konferencii*; Rossijskij Universitet Druzhby Narodov: Moskva, Russia, 2019; pp. 73–76. Available online: https://elibrary.ru/item.asp?id=42395856.

[25] Yesayan, Z.V.; Rakova, T.V.; Lunev, M.A. On the Effectiveness of Therapeutic Treatment of Apical Periodontitis Using Some Filling Materials. *Mod. Sci. Curr. Probl. Theory Pract. Ser. Nat. Tech. Sci.* **2019**, *6*, 154–158. [View Online]

[26] Anar, F.; Rashid, M.H.A.; Islam, K.M.; Rahman, R.; Rahman, MM; Khanam, S.R.; Rahman, M.M. An Evaluation of the Effectiveness of Calcium Hydroxide as A Root Canal Sealer Constituent. *Community Based Med. J. (CBMJ)* **2023**, *12*, 141–149. [CrossRef]

[27] Tarasenko, S.V.; Grigor'yanc, L.A.; Gor, I.A.; Medvedeva, I.V.; Pogosyan, G.R. Analysis of the Antibacterial Effect of Filling Materials for Permanent Channel Obstruction. *Ross. Stomatol. Zhurnal* **2018**, *22*, 229–232. (In Russian) [View Online]

[28] Greenwood, N.N.; Earnshaw, A. *Chemistry of the Elements*, 5th ed.; Laboratoriya Znaniy: Moscow, Russia, 2021; Volume 1, 664p. Available online: https://vk.com/wall-90182650_1019. (In Russian)

[29] Best, S.M.; Porter, A.E.; Than, E.S.; Huang, J. Bioceramics: Past, Present and for the Future. *J. Eur. Ceram. Soc.* **2008**, *28*, 1319–1327. [CrossRef]

[30] Glinkin, V.V. Method of Filling with Trioxident Orthograde of Root Canals of Teeth with Destroyed Apical Constriction. In *Medical Science and Practice in the Conditions of Modern Transformation Processes: Collection of Scientific Works of Participants of the International Scientific and Practical Conference*; Lviv Medical Society: Lviv, Ukraine, 2021; pp. 11–13. Available online: https://repo.knmu.edu.ua/server/api/core/bitstreams/a6b952fe-d4cc-4154-beb4-a9fb319685ed/content. (In Ukrainian)

[31] Glinkin, V.V. Method of Filling with Trioxident Orthograde of Root Canals of Teeth with Destroyed Apical Constriction. In Proceedings of the Medical Science and Practice in the Minds of Current Transformation Processes: A Collection of Scientific Works of Participants in the International Scientific and Practical Conference, Lviv: GO "Lviv Medical Society", Moscow Lviv, Russia, 23–24 April 2021; pp. 11–13. (In Ukrainian)

[32] European Endodontic Society. Report of the European Endodontic Society Consensus on Core Quality Indicators in Endodontic Treatment. *Endodontia Today* **2001**, *1*, 3–12. (In Russian) [View Online]

Disclaimer/Publisher's Note: The views expressed in this article are those of the author(s) and do not necessarily reflect the views of the publisher or editors. The publisher and editors assume no responsibility for any injury or damage resulting from the use of information contained herein.