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**Research Article**

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

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## Abstract

**Introduction:** High-quality root canal obturation and the correct choice of sealant are the main factors preventing its reinfection. A wide lumen of the apical foramen, often of inflammatory genesis, actually excludes the possibility of root canal sealing. **Objective:** To conduct, using SEM, morphological studies of endo-sealers used for filling canals of teeth with destructive forms of periodontitis and the quality of sealing of the root canal with destroyed apical constriction. **Materials and methods:** Scanning electron microscopy (SEM) methods were used to study the morphology and microstructure of dental samples and filling materials. To verify the size of the apical foramen, we developed a method using a gutta-percha pin. Three materials were used as endosealers: Foredent, Sealapex, Trioxident. To treat patients with partially and severely destroyed apical constriction, we proposed and introduced into practice a technique of orthograde root canal filling with Trioxident cement. Sections of 15 roots of extracted teeth were prepared and divided into 3 groups depending on the endo-sealant 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 presence of the hydration process in Trioxident cement allows us to assume that its use for orthograde root canal filling will prevent the resorption of the filling material in the apical part of the tooth root and prevent the progression of the pathological process in the periodontium.

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

**1. Introduction.** To date, the frequency of patient visits due to the need for endodontic dental treatment does not tend to decrease. Periodontitis is an indication for tooth extraction in 50% - 80% of patients [1]. According to some data, patients with destructive forms of periodontitis make up 30-45% of the total number of those seeking endodontic care [2]. A.V. Durov (2018) believes that at an outpatient dental appointment, these forms of periodontitis make up 20-56% of the total number of those seeking care [3].

The success of endodontic treatment is based on three fundamental principles: thorough cleaning, effective disinfection, and obturation of the root canals [4, 5]. Despite the importance of the first two points [6], one should not forget about root canal obturation [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) argue that it is necessary to analyze the risk factors for endodontic treatment, since Complications may occur in 57.8% of cases [9].

According to the quality indicators of the European Society of Endodontics (ESE), the purpose of root canal obturation is to prevent the penetration of microflora and fluid into the root canal system. In order to achieve compliance with the quality requirements of ESE, it is necessary to obturate not only the apical opening, but also the entire root canal system. According to research by L.Z. Jovanović and B.V. Bajkin (2021), MTA demonstrates a satisfactory degree of marginal adaptation [10].

Based on the analysis of previously conducted studies, it can be concluded that high-quality obturation of the root canal and the correct choice of sealant are the main factors preventing its reinfection [11, 12]. This, in turn, allows for a lasting therapeutic effect in the long term of treatment, and in many cases, to achieve regeneration of periodontal tissues [13, 14, 15].

Today, the diagnosis dictates a treatment plan, the correct choice of which determines the regenerative processes in the periodontium [16]. A correctly determined working length of the root canal has a great influence on all stages and results of periodontitis treatment [17]. In destructive forms of periodontitis, a large diameter of the apical foramen actually excludes the possibility of accurately determining the working length of the canal, and X-ray examination methods do not always allow determining the presence of destroyed apical foramen [18]. In such cases, the correct determination of the working length of the root canal is not guaranteed, and, consequently, the quality of instrumental, medicinal treatment, and sealing is also compromised.

Thus, the high number of requests for endodontic care, the low percentage of curability of teeth with destroyed apical constriction, the lack of specific recommendations for the use of various root filling materials, makes it relevant to develop methods of instrumental, medicinal treatment of root canals and clear indications for the selection of root filling materials [19].

This study is part of an extensive clinical and laboratory study that allowed us to analyze endo-sealants and substantiate a differentiated approach to the treatment of teeth with periapical pathology.

## 2. Material and Methods

To study the morphology, microstructure of dental samples (extracted teeth) and filling materials, scanning electron microscopy (SEM) methods were used in the Department of Physics and Diagnostics of Advanced Materials of the 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 material was studied using electronic signals of both classes, SEI and BEI. The standards used for quantitative analysis are certified and supplied by JEOL. Upon completion of the study of the samples, the obtained photographs were analyzed.

After completing the study of the samples, the obtained photographs were analyzed using the Excel program.

### 2.1. Verification of the Size of the Apical Foramen

To conduct research on the quality of root canal obturation of teeth with destroyed apical constriction, according to the method we developed [20], we prepared sections of 15 roots of extracted teeth with destroyed apical constriction, which, depending on the endo-sealant used, were divided into 3 groups. Endodontic treatment was performed on patients whose diagnosis corresponded to the ICD-10 codes: K04.5-K 04.8. Examination and treatment of patients was carried out with their written consent. 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 patient's interests or harm to his health. Before starting instrumental treatment of the root canal, its approximate working length was determined. It was decided to divide the patients into three groups: with preserved constriction, with partially destroyed and severely destroyed, which would correspond to the radiographic criteria of 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.

To verify the size of the apical opening, conical gutta-percha or X-ray contrast temporary filling material based on calcium can be used. For this purpose, we have developed a method using a 25.06 gutta-percha pin. The gutta-percha pin was shortened with scissors by 1 mm until a stop was obtained in the apex area. To determine the diameter of the apical opening, a calculation formula was developed and proposed:

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

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 facilitates the selection of a file for forming an apical stop in teeth with destroyed apical constriction.

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

After reaching the apical stop with a calibrated gutta-percha pin, an X-ray examination was performed and, upon completion of standardized chemo mechanical treatment using a canal filler, the root canal was sealed with a calcium-containing preparation for temporary sealing along the entire working length. 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 protocol of endodontic treatment remains unchanged [23] and includes the following points:
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 are 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. In preparation for the examination, the extracted teeth are placed in a silicone mold made of C-silicone mass, for example, Zeta plus, according to the instructions for use.

After the mass has hardened, the teeth are prepared according to the standard technique for endodontic treatment, according to the approved unified protocol, the technique 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. Fill the root canals of the tooth according to the instructions for use of the specific material being studied.
7. Seal the carious cavity hermetically with cement, for example zinc phosphate “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 must harden in the root canals according to the time specified in the instructions.
10. Make a tooth grind according to the method described below.

### 2.4. Method of preparing a tooth section (for SEM examination):

Longitudinal (transverse) sawing of the root of the extracted tooth is performed with a diamond separating disk in such a way as to avoid overheating of the tooth in order to prevent cracking of the sample.
2. The resulting sample for examination is filled with epoxy resin (resin: hardener ratio 9:1). After its polymerization (at least 24 hours), 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 is 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 is 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, endo-sealers belonging to three different groups were used: Foredent, Sealapex, Trioxident.

1. "Foredent" - contains paraformaldehyde (19-24%), which is a strong antiseptic. This is the basis of its disinfectant properties. But at the same time, it has strong mutagenic, teratogenic, toxic effects. It has strong mutagenic, teratogenic, toxic effects. In addition, it was previously established that when this endo-sealant is introduced into the periapical space, as a rule, an inflammatory process develops, which is accompanied by the occurrence of severe post-filling pain in patients, lasting from several minutes to several days, and sometimes the progression of the pathological process in the periodontal tissues in the long term [24].

2. The second group of root canals was filled with “Sealapex”, a material produced in the USA by Kerr Hawe. It is used in combination with gutta-percha and silver pins. The filling material contains calcium and zinc oxides, zinc steroid, titanium dioxide, barium sulfate, and submicron silicone glass. It hardens in a humid environment.

Sealapex is a eugenol-free calcium hydroxide-based endodontic filling material. It hardens in a humid environment. Experimental studies on animal teeth showed that Sealapex promoted apical closure by depositing secondary cement in cases where the root canal filling was 1 mm above 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 has a number of disadvantages. Sealapex only hardens completely after three days. More than 3% of its mass and liquid are lost within 24 hours, and the material does not meet the requirements of ISO 6876-86 in these parameters. However, the antibacterial effect of the material is short-lived and disappears over time under the influence of tissue fluid [26]. This is confirmed by the observations made by S.V. Tarasenko et al. (2018) who analyzed the antibacterial effects of filling materials based on calcium hydroxide [27].

Foredent was used to fill the canals using a root canal filler. Sealapex was used as a sealer in conjunction with gutta-percha points using the lateral condensation method.

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 consists of calcium oxide, which, when interacting with water, turns into calcium hydroxide, providing a highly alkaline environment (pH 12.8) of the cement: 3CaOSiO2 + nH2O = 2CaOSiO2 2H2O + Ca (OH) 2 + (n-3) H2O. The composition includes oxides of silicon, aluminum, bismuth and copper-calcium hydroxide as a bacteriostatic additive. N. Greenwood (2017) claims that aluminum oxide, due to its strong crystal lattice, is chemically inert and insoluble [28]. Being bio inert materials, aluminum oxide and zirconium dioxide cause a minor reaction of surrounding tissues [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. As a result of mixing cement with water, a chemical reaction occurs. The product of cement hydration is a gel. This is a long-term chemical reaction and over time, the strength of the cement only increases. This is the reason for one of the most important qualities of the endo-sealant - its adhesive ability [30]. Previously, this material was most often used for retrograde root canal filling after resection of the root apex and with its 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 fill the canal to the mouth using a canal filler and condensing it. X-ray quality control of root canal filling was performed. A cotton swab moistened with sterile water was left at the root canal mouth for 24 hours and the tooth cavity was hermetically sealed with a temporary filling material. During the next visit, the tooth cavity was filled with a permanent material [31].

Filling of root canals with other sealants in all groups of patients was carried out according to the instructions for these materials. Dispensary observation of patients after treatment was carried out according to the Directive 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. The category of teeth with signs of severe resorption, visualized on the X-ray as distinct X-ray transparent depressions or shortening of the root tip.

To verify the size of the apical opening, it is possible to pre-measure the size of the apical opening using a measuring scale of a radiovisiograph or on a section of a computer tomogram; it is possible to use an X-ray contrast temporary filling material based on calcium hydroxide. When using the tactile method and the periodontal sensitivity method, it is possible to incorrectly determine the working length of the canal.

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

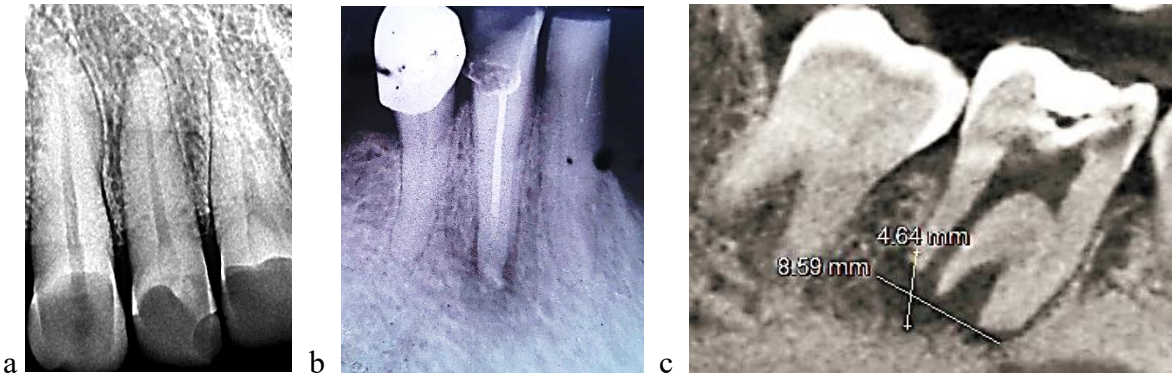


**Figure 1.** Radiograph of tooth 12 without signs of resorption (a). Radiograph of tooth 42 with signs of moderate resorption (b). CBCT section of tooth 47 with signs of severe resorption (c).

To obtain more accurate data when verifying the size of the apical foramen in the absence of a radiovisiograph and CBCT, it was proposed to use a method for calculating the size of the apical foramen using a gutta-percha pin (Figure 2).

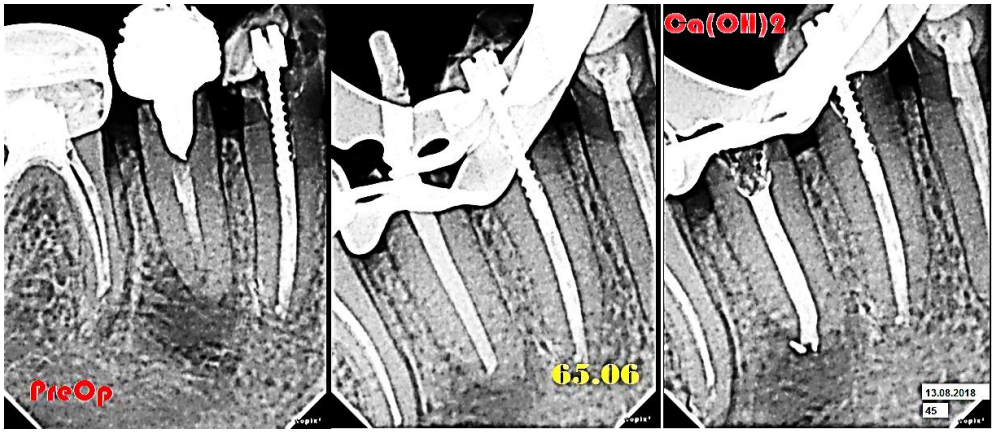


**Figure 2.** Example of determining the apical stop with a calibrated gutta-percha pin. Radiographs of tooth 45: initial situation (a); image with a calibrated gutta-percha pin of 06 taper (b); image with a temporary calcium-containing material in the root canal (c)

The morphological characteristics of the materials under study were studied using monochrome images obtained with a SEM.

To unify this study, the size of the micro particles that comprise the endo-sealants under study was measured. According to the classification of colloid chemistry, they can be classified as medium-dispersed or finely dispersed systems (Figure 3).

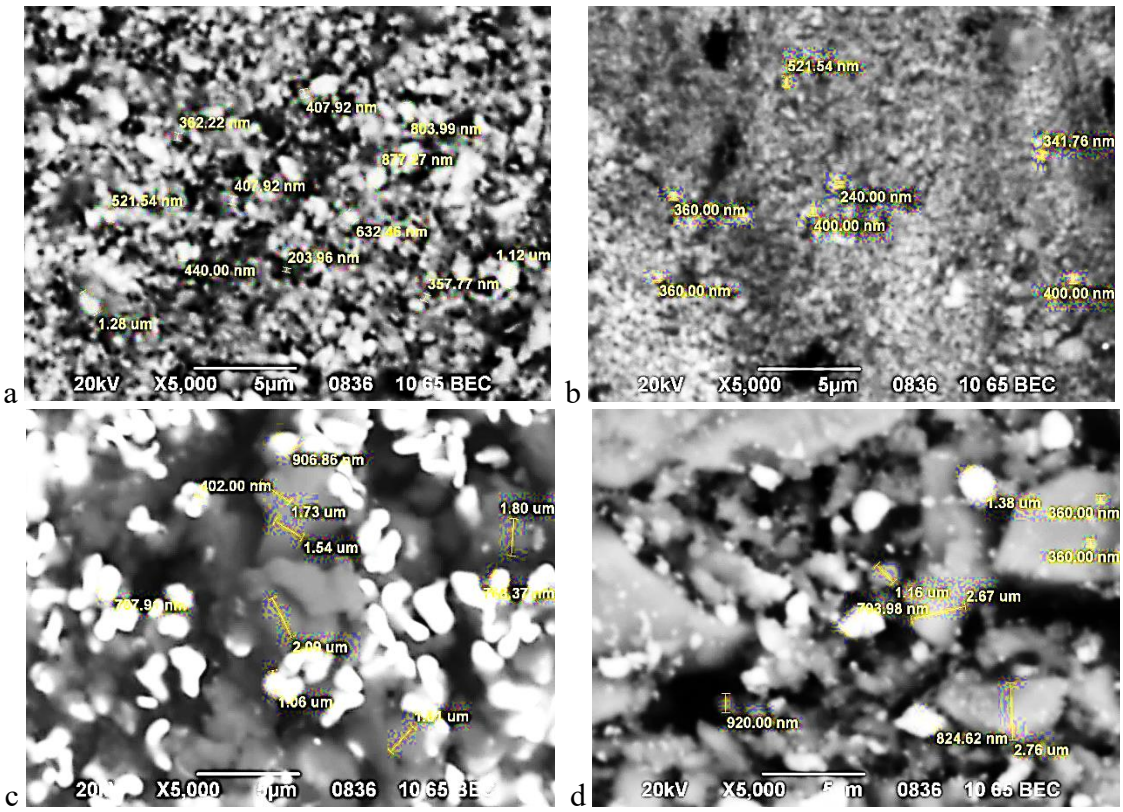


**Figure 3.** Morphology of filling materials with particle sizes indicated: Foredent (a), gutta-percha pin (b), Sealapex (c), Trioxident (d). SEM. BEC. Magnification 5000x

According to the obtained SEM results (Figure 3 a, 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.

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.

Despite the fact that these endo-sealants can be classified as homogeneous, there is no tight fit between their micro particles.

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 data obtained allow us to believe that Trioxident is a heterogeneous material, since the particle sizes range from larger (>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. In our opinion, such a combination of micro particles contributes to an increase in the strength characteristics of the material. In addition, when studying Trioxident, we observed a hydration process with the formation of crystal hydrates (Figure 4).

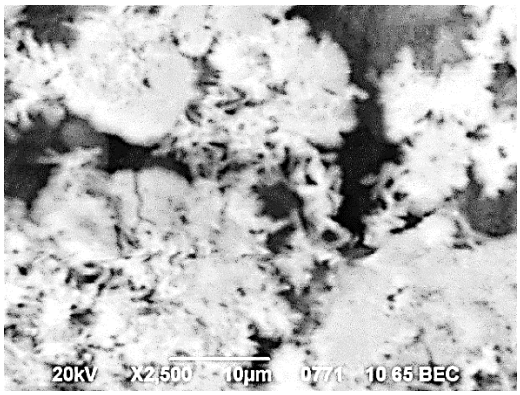


**Figure 4.** The process of hydration with the formation of crystal hydrates in Trioxident in the apical part of the root canal. SEM. VES. Magnification: x2500

Using SEM, we found that the hydration process is observed already in the first days after filling and lasts for quite a long time, increasing the strength characteristics of the material. 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 to maintain moisture in the filling material and, accordingly, helps to strengthen it.

During the morphological study of endo-sealers using the SEM method, micro cracks in the filling material are clearly visible.

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 has a homogeneous finely dispersed structure with single small pores.

Sealapex is a material of uniform consistency with an insignificant amount of micro cracks (~7.32 μm), but a large content of micropores (~0.86 μm). It was noted that the micropores in the first two sealers are approximately the same size.

Precisely because Trioxident includes micro particles of different sizes, they did not fit tightly to each other and there were single micro cracks (~1.11 μm) and micropores (~1.31 μm) in it. At first glance, they could be mistaken for large micropores. But the distance between these micro particles is filled with a gel-like mass. Unlike the previous materials, they were not voids. Therefore, in the case of Trioxident, we have no right to talk about the presence of micropores in the structure of the material itself. Small crystals are combined into a fine-pored homogeneous structure that

determines the strength characteristics of the material. During the study, it was noted that in Foredent and Sealapex, the micropores are almost the same size, which is shown in Figure 5.

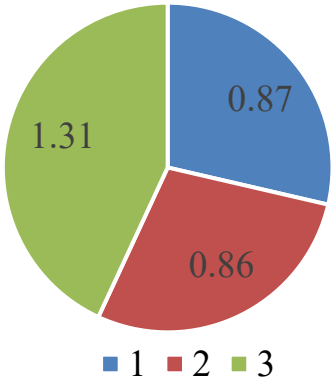


**Figure 5.** Average micropore sizes and distances between micro particles in the filling materials under study (in micrometers).

Note: 1 – Foredent; 2 – Sealapex; 3 – Trioxident

The average size of micro-gaps 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). And then, when using Trioxident, micro-gaps 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 has an intermediate 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. We visually note a tight fit of the endodontic sealant to the walls of the apical opening everywhere (Figure 6 a, b).

The opposite picture of the density of adhesion of root canal sealers was observed at high magnification in all samples of the studied materials, which is demonstrated in Figure 7 (a-c), where micro-gaps between the canal wall and the endodontic material are clearly visualized.

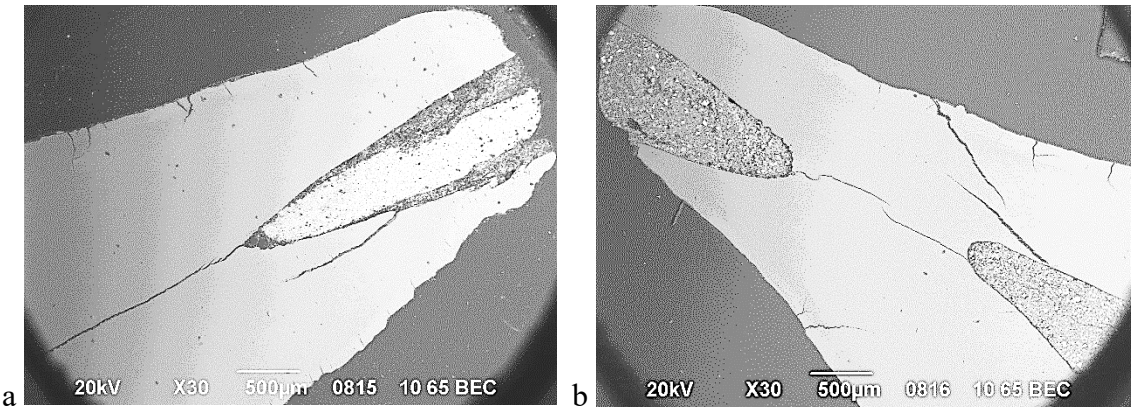


**Figure 6.** Adjacency of the studied filling materials in the apical region of the root canal: Sealapex with a gutta-percha pin (a), Trioxident (b). SEM. Contrast in BEC electrons. Magnification: x30

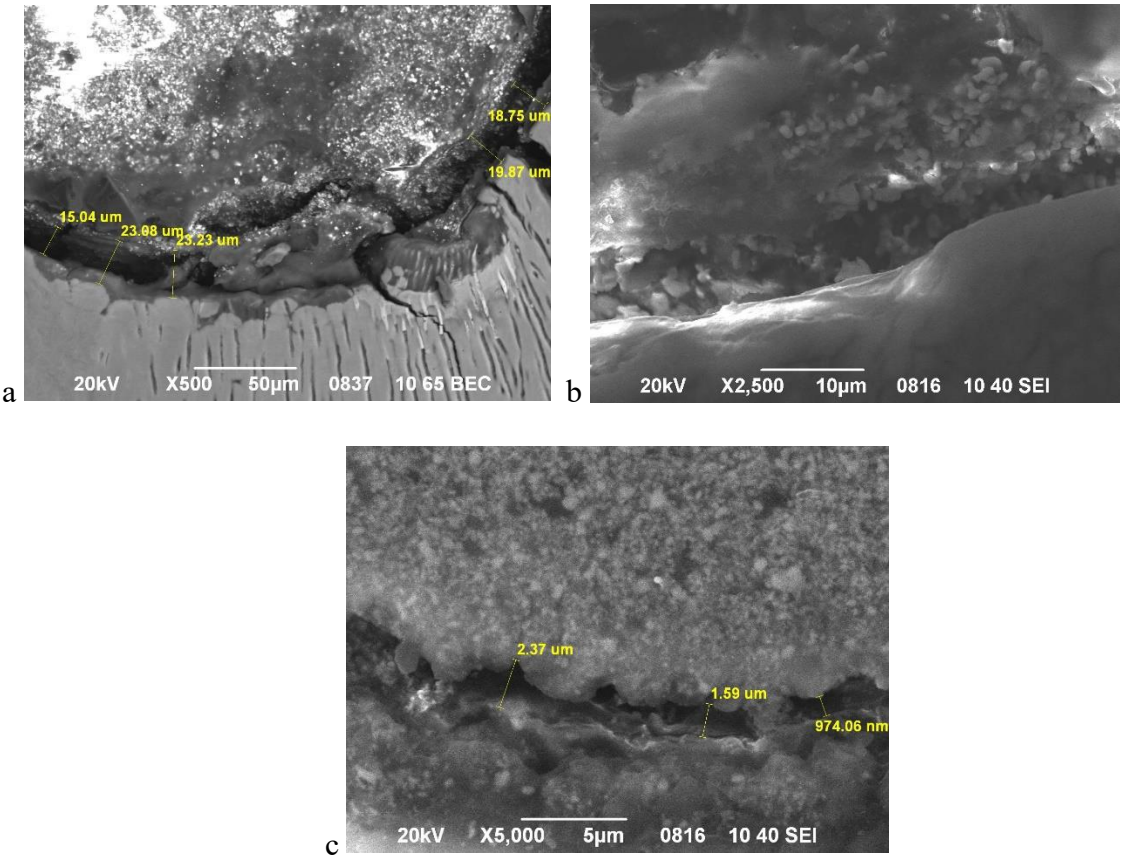


**Figure 7.** Micro gap between the canal wall and the filling material under study: Foredent (a), Sealapex (b), Trioxident (c). SEM. Contrast in BEC (a) and SEI electrons (b, c). Magnification: x1000 (a), x2500 (b), x5000 (c)

During the examination of the sections, it was found that the worst parietal adhesion was observed everywhere when using 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 an insignificant amount of ~ 7.17-14.07 µm. In the middle third of the roots and closer to the apex, a tight fit of the filling material to the canal wall was noted along the entire length. But in the area of wide apical openings this fit was 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. In our opinion, this is due to the lack of liquid necessary for strengthening the material in this area (Figure 8).

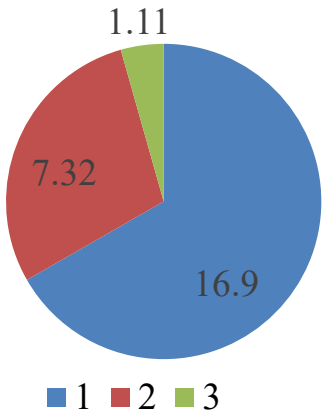


**Figure 8.** Average sizes of microcracks along the border of filling materials and root canal walls (in micrometers).

Note: 1 – Foredent; 2 – Sealapex; 3 – Trioxident

In vitro studies of teeth with destroyed apical constriction sealed with Foredent and Sealapex revealed leakage of the endosealant from the apical foramen in all cases (Figure 9, 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.

When using Trioxident, leakage of the material was observed in 40% of cases with a tight fit 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 called "clean", since it is not possible to create all the 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.

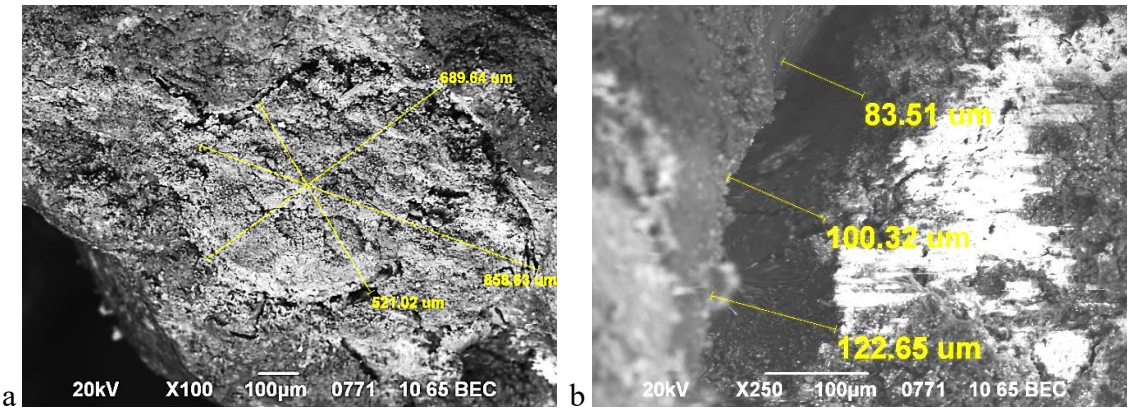


**Figure 9.** View of the apical part of the root after filling (a). Micro gap between the canal wall and the Foredent filling material on the outer surface of the root (b). SEM. VES. Magnification: x100 (a), 250 (b).

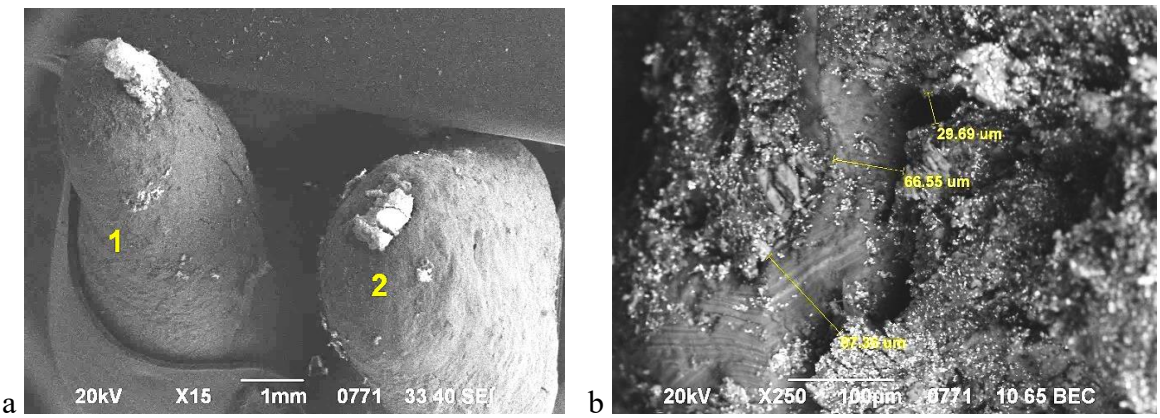


**Figure 10.** View of the apical part of the root after filling (a). Micro gap between the canal wall and the filling material Sealapex with gutta-percha pins on the outer surface of the root (b). SEM. SEI and BEC. Magnification: x15 (a), x250 (b).

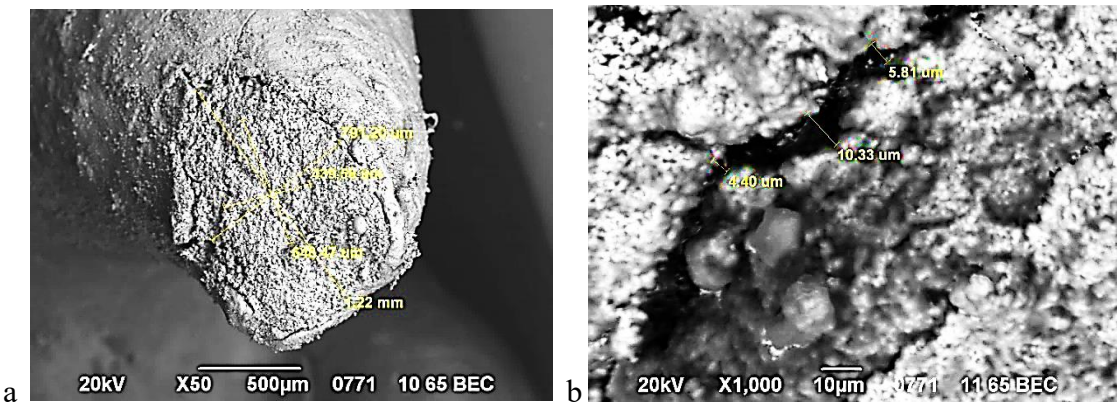


**Figure 11.** View of the apical part of the root after filling (a). Micro gap between the canal wall and the Trioxident filling material on the outer surface of the root (b). SEM. VES. Magnification: x.50 (a), x1000 (b).

**4. Discussion.** Data on the results of conservative treatment of teeth with destroyed apical constriction are ambiguous. Endodontic treatment today solves complex medical problems. For these purposes, we have developed and implemented in practice a method for verifying the size of the apical opening. These calculations allow the doctor to verify the size of the apical opening in order to subsequently determine the choice of endodontic sealant. An important component of the success of endodontic treatment is high-quality filling of the root canals of teeth on a permanent basis using certain endodontic sealants. Failures of endodontic treatment, in most cases, are associated with the level of root canal filling, especially in cases where the filling was carried out with a discrepancy between standard treatment or with other various therapeutic factors. It is necessary to selectively approach the choice of root filling material depending on the clinical situation.

Before starting treatment of teeth with apical forms of periodontitis, the doctor must clearly understand the degree of destruction of the apical constriction in order to subsequently determine the choice of the most effective endo-sealer in each specific situation.

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 most optimal use in filling teeth depending on the state of the apical constriction.

Depending on the state of the apical opening, it is recommended to divide teeth with destructive apical periodontitis into three groups. For teeth with preserved and partially destroyed apical constriction, Sealapex with gutta-percha pins (or similar material based on calcium hydroxide) is recommended for use, since it has an osteoinductive effect, promoting healing of the lesion. For a group of teeth with severely destroyed constriction, it is recommended to fill the root canals with Trioxident (or other cements of the MTA group) using the orthograde method. It allows for high-quality obturation in a humid environment, creating a kind of monoblock, firmly connecting with the wall of the root canal. We do not recommend the use of Trioxident for filling teeth with preserved apical constriction due to the high risk of seal failure in the absence of moisture in the root canal and the difficulties of its application in this case.

The presence of micropores in endo-sealants, cracks in the loose fit of the material to the walls of the root canal allow us to assume that these factors can contribute to reinfection of the root canal in the long term.

**5. Conclusions:** Optimization of root canal obturation is the choice of endodontic sealant for the treatment of teeth with different states of apical constriction. The presence of microdefects in the materials under consideration should lead to a decrease in sealing and increased permeability for both microflora and its 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 with a destroyed apical constriction showed a high result due to the hydration process in the cement and tight marginal adhesion. We assume that this will prevent the resorption of the filling material in the apical part of the tooth root and prevent the progression of the pathological process 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. And in this situation, the interaction of the endo-sealant with the surrounding tissues comes to the fore.

Depending on the condition of the apical opening, it is recommended to divide teeth with destructive apical periodontitis 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. It allows achieving high-quality obturation in a humid environment, creating a kind of monoblock firmly connecting with the wall of the root canal. We do not recommend the use of Trioxident for filling teeth with preserved apical constriction due to the high risk of sealing failure in the absence of moisture in the root canal and the difficulties of its introduction in this case.

This study helps the practitioner to choose a specific endo-sealant when treating teeth with periapical pathology based on knowledge of the degree of destruction of apical constriction and the morphology of endo-sealants. Further clinical studies confirmed by statistical methods will make the treatment process more predictable.

**List of Abbreviations:**

- Scanning electron microscopy (SEM)
- European Society of Endodontics (ESE)
- Mineral Trioxide Aggregate (MTA)
- Cone-Beam Computed Tomography (CBCT)

**Author contributions:**
V.V. Glinkin: conceptualization, research, software development, writing — review and editing, visualization; V.V. Glinkina: research, data processing, writing — initial draft preparation. 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**
Not applicable.

**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 patient's interests or harm to his health.

## Conflicts of interest

All authors declare that they have no conflicts of interest.

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## References

[1] A.V. Mitronin, «Endodontic treatment of pulp and periodontal diseases. Part 1. Aspects of the use of antibacterial drugs» *Endodontiya Today*, no. 1, pp. 9-15, 2012. (Russian)
[2]. A.Yu. Rozenbaum, "Optimization of complex treatment of patients with chronic apical periodontitis: doctoral thesis". Samara, 2016. URL: https://samsmu.ru/files/referats/2016/rozenbaum/avtoreferat.pdf.].
[3] A.V. Durova. Conservative treatment of patients with destructive forms of apical periodontitis with calcium orthophosphate-based materials: doctoral thesis. Tver', 2018. URL: https://docviewer.yandex.ua/view/86597640/
[4] G.H. Li, L.N. Niu, L.C. Selem, A. A. Eid, B.E. Bergeron, J.-H. Chen, D.H. Pashley, F.R. Tay, "Quality of obturation achieved by an endodontic core-carrier system with crosslinked gutta-percha carrier in single-rooted canals" *Journal of Dentistry*, vol 42, no. 9, pp. 1124-1134, 2014.
[5] Jovanović L. Z., Bajkin B. V. "Scanning electronmicroscopy analysis of marginal adaptation of mineral trioxide aggregate, tricalciumsilicatecement, and dental amalgamas a root end filling material" *Microsc. Res. Tech*, 2021, vol. 84, no 9, pp. 2068–2074.
[6] M. Haapasalo, U. Endal, H. Zandi, J. Coil, "Eradication of endodontic infection by instrumentation and irrigation solutions" *Endodontic Topics,* no. 10, pp. 77-102, 2005. [Scientific Research].
[7] B.M. Gillen, S.W. Looney, L.S. Gu, B.A. Loushine, R.N. Weller, R.J. Loushine, D.H. Pashley, F.R. Tay, "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" *Journal of Endodontics*, vol. 37, pp. 895-902, 2011.
[8] Gor, I. A. "Treatment of patients with a foreign body (filling material) in the jaw bone and soft tissue": specialty 14.01.14 "Dentistry": dissertation for the degree of candidate of medical sciences. - Moscow, 2020, 150 p.] (Russian).
[9] D. Huang, X. Wang, J. Liang *et al*. "Expert consensus on difficulty assessment of endodontic therapy" *International Journal of Oral Science,* 2024, vol. 16, no 22, pp. 1–11. doi: 10.1038/s41368-024-00285-0
[10] P. Amjroso-Silva, S. C. Brasil, A. R. Peres *et al*. "Influence of sealer type on treatment outcome of teeth with apical periodontitis: a systematic review" Braz. Dent. J., 2023,vol. 34, no 5, pp. 1–21. doi: 10.1590/0103-6440202305471

[11] Silva E. J. N. L., de Lima C. O., Barbosa A. F. A., *et al*. "Efficacy of an arrow-shaped ultrasonic tip for the removal of residual root canal filling materials" Aust. Endod. J., vol. 47, no. 3, pp. 467–473. 2021. doi: 10.1111/aej.12505
[12] D. Ricucci, L.M. Lin, L.S. Spaongberg, "Wound healing of apical tissues after root canal therapy: a long-term clinical, radiographic, and histopathologic observation study" *Oral Surgery Oral Medicine Oral Pathology Oral Radiology & Endodontics*, vol. 108, pp. 609-621, 2009.
[13] Glinkin V.V. "Comparative analysis of endo-sealants and a differentiated approach to the treatment of teeth with periapical pathology (clinical and laboratory research)": specialty 3.1.7. Dentistry dissertation for the degree of candidate of medical sciences. - Donetsk, 2025, 203p. (Russian)
[14] C. Estrela, R. Holland, C.R. Estrela, A.H.G. Alencar, M.D. Sousa-Neto, J.D. Pécora, "Characterization of successful root canal treatment" *Braz. Dent. J*., vol 25, no. 1, pp. 3-11, 2014.
[15] G.H. Li, L.N. Niu, W. Zhang, M. Olsen, G. De-Deus, A. A. Eid, J.-H. Chen, D.H. Pashley, F.R. Tay, "Ability of new obturation materials to improve the seal of the root canal system: a review" *Acta Biomaterialia,* no. 10, pp. 1050-1063*,* 2014.
[16] Dash G., Mishra L., Singh N. R., et al. "Prevalence and Quality of Endodontic Treatment in Patients with Cardiovascular Disease and Associated Risk Factors" *J. Clin. Med.*, vol. 11, no. 20, pp. 6046, 2022. doi: 10.3390/jcm11206046
[17] L.P. Gerasimova, S.M. Aletdinova, "Diagnosis and comprehensive treatment of acute chronic apical periodontitis" *Endodontiya Today*, no. 1(29), pp. 6-9, 2014.
[18] Antanyan, A.A. Effective Endodontics (2nd ed., revised and expanded). Moscow: Medical Information Agency Publishing House LLC, 2017. 232 p., illustrated (Russian).
[19] E. Hidoussi, Z. M. Al-Hawwaz, N. Zokkar, N. Douki. Healing of periapical lesion after root canal treatment: A case report" *Indian Journal of Conservative and Endodontics*, 2021. vol. 6, no 4, pp. 228–232.
[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. Published February 24, 2021. Bulletin No. 8. [in Ukrainian].
[21] M. Laux, P.V. Abbott, G. Pajarola, P.N. Nair, "Apical inflammatory root resorption: a correlative radiographic and histological assessment" *International Endodontic Journal*, vol. 33, pp. 483-493, 2000.
[22] Glinkin V.V. "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". Identifikator elektronnogo dokumenta: CR0124260321. Dostupno po https//sis.ukrpatent.org] (Russian).
[23] Gutman, J. L. Problem solving in endodontics: prevention, diagnostics and treatment / J. L. Gutman, T. S. Dumsha, P. E. Lovell; trans. from English. - Moscow: MEDpress-inform, 2008. 592 p.
[24] S.V. Tarasenko, I.A. Gor, "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, 2019, pp. 73–76.] (Russian).
[25] Z.V. Esayan, T.V. Rakova, M.A. Lunyov, "The effectiveness of therapeutic treatment of apical periodontitis with the use of certain filling materials" *Sovremennaya nauka: aktual'nye problemy teorii i praktiki. Seriya: Estestvennye i tekhnicheskie nauki*, no. 6, pp. 154-158, 2019 (Russian).
[26] Kovach, L. V., & Romanenko, O. G. Planning therapeutic tactics for complicated caries in permanent teeth with incompletely formed root apices (literature review). Visnyk Stomatolohii, no. 3, pp. 92–97, 2008. [in Ukrainian]
[27] S.V. Tarasenko, L.A. Grigor'yanc, I.A. Gor, I.V. Medvedeva, G.R. Pogosyan, "Analysis of the antibacterial effect of filling materials for permanent channel obstruction" *Rossijskij stomatologicheskij zhurnal*, t. 22, no. 5, pp. 229-232, 2018. (Russian)

[28] Greenwood, N. N., & Earnshaw, A. *Chemistry of the Elements* (Vol. 1, 5th ed., Russian translation). Moscow: Laboratoriya znaniy, 2021, 664 p. (Russian)
[29] S.M. Best, A.E. Porter, E.S. Than, J. Huang, "Bioceramics: past, present and for the future" *Journal of the European Ceramic Society*, vol. 28, no. 7, pp. 1319–1327, 2008.
[30] Ghouchani, T. Z., Farhadpour H., Mohammadi N. "Effect of Root Canal Filling Materials and Pretreatment with Solvents on the Shear Bond Strength of Composite Resin with Primary Tooth Dentin." Biomed. Res. Int., 2021, vol. 2021, pp. 5534294. doi: 10.1155/2021/5534294.
[31] V.V. Glinkin, "Method of filling with trioxident orthograde of root canals of teeth with destroyed apical constriction" *Medichna nauka ta praktika v umovah suchasnih transformacijnih procesiv: zbirnik tez naukovih robit uchasnikiv mizhnarodnoï naukovo-praktichnoï konferenciï*. L'viv, 2021, pp. 11-13. (Russian)
[32] " European Endodontic Society. Report on the agreed opinion of the European Endodontic Society on the main quality indicators for endodontic treatment. Endodontia Today, no. 1, pp. 3–12, 2001. [in Russian]