# Remote clinical results of the use of endo-sealants in the treatment of teeth with destructive forms of apical periodontitis.

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**Abstract.** Radiographic examination methods are used to assess the quality of endodontic treatment. The search for new methods for objectively assessing the results of endodontic treatment remains relevant. The development of appropriate accessible standards for assessing the quality of treatment will allow a practicing physician to objectively evaluate the results of their work. **Objective:** to evaluate the effectiveness of treating teeth with periapical pathology based on the state of apical constriction, substantiating the choice of obturation material, based on clinical and radiographic examination methods. **Material and methods.** The study involved 156 participants who underwent treatment for 194 teeth (365 roots) with destructive forms of apical periodontitis in the acute stage. The study utilized a retrospective cohort study and a randomized cohort study. Patients were assigned to groups based on the type of permanent root canal filling materials used and the degree of apical constriction destruction. Long-term outcome studies were conducted over periods ranging from 6 months to 4 years. For radiographic examination, the following were used: an intraoral X-ray diagnostic dental unit 5D2, a radiovisiograph SOPIX 2 (Acteon Group France), and CBCT in parallel technique. Root canal filling was performed with Foredent, Sealapex, and Trioxident. Foredent was used to fill the root canals of 82 teeth (42.27%), Sealapex – 94 teeth (48.45%), and Trioxident – 18 teeth (9.27%). The teeth were divided into three groups based on the degree of apical constriction destruction. The periapical index (PAI) and the "Periapical Index for Assessing the Quality of Endodontic Treatment of Destructive Periodontitis," which we developed, were used to compare and contrast the study data. **Results.** The PAI value was assessed as the average for each group. Participants were examined from 6 months to 4 years after completion of treatment. In case of destroyed apical constriction, the failure rate of endodontic treatment after using Foredent reaches 80%, which is 5.3 times worse than the indicators of Sealapex and 8.9 times worse than Trioxident. **Conclusions.** The best treatment results were achieved in the group with preserved apical constriction using Sealapex and gutta-percha pins (11.5% more effective than Foredent ($p < 0.005$)). In the group with partially destroyed constriction, both Sealapex and Trioxident demonstrated equal success rates. Over a period of up to 4 years, the success rates reached 93% and 89%, respectively. However, for Foredent, the effectiveness was only 35% ($p < 0.05$), which is due to disrupted canal obturation. In teeth with destroyed apical constriction, the best result was achieved with Trioxident (91% over a period of one year and over 4 years ($p < 0.05$)). Positive results in this group of teeth were achieved with Sealapex – from 88% to 80%, and with Foredent – from 47.14% to 8%, respectively.

**Key words:** apical periodontitis; radiographic examination; periapical index; endo-sealants; trioxident; foredent.

## 1. Introduction.

Despite the latest scientific advances, the diagnosis of periodontal pathology still poses challenges [1, 2]. According to some authors, complications during endodontic treatment occur in 15-60% of cases. Traditionally, endodontic failure is believed to be caused by endodontic infection. The inflammatory response in the periodontal region is similar to that elsewhere in the body. If the irritant is removed—

that is, the root canal is cleaned, shaped, and filled—healing occurs similarly to healing in any other part of the body. It is advisable to evaluate the success of endodontic treatment dynamically at regular intervals, using not only clinical but also radiographic data [3, 4, 5]. In this case, the condition of the hard tissues of the tooth, periapical tissues, and bone tissue are assessed. Radiographic studies allow us to identify and evaluate potential errors not only during the treatment itself, but also its long-term results [6, 7]. Two-dimensional display of three-dimensional structures significantly impairs the recognition of periapical pathology on radiographs; therefore, for these purposes, it is better to use cone beam computed tomography (CBCT), which allows for obtaining an image with a lower risk of distortion of the results [8]. A higher diagnostic value of CBCT is achieved due to the resulting three-dimensional image [9, 10, 11], which allows for more accurate determination of the size of the periapical lesion [12, 13]. The most effective combination of CBCT with intraoral radiography is for this purpose. CBCT allows for detailed determination of the heterogeneity of root canal (RC) filling with endodontic sealant (ES) [14]. Therefore, it is crucial to expand the capabilities of dental X-ray diagnostics with additional CBCT studies [15].

In addition, it is necessary to take into account that radiographic assessment of the condition of periodontal tissues is convenient in descriptive medicine, but evidence-based medicine requires formalization of the obtained data and objective coverage of the dynamics of changes after treatment. The generally accepted standard for analyzing the quality of treatment performed in radiography is the criterion defined by Strindberg in 1956 [16]. The first radiographic description of signs of pathological changes in periodontal tissues in a scoring system was proposed by Orstavik D. et al. in 1986, which was called the "Periapical Index" [17]. Since then, the index has been modernized several times.

Currently, the quality of endodontic treatment is recommended to be assessed based on the European Society of Endodontology Guidelines. These recommendations are based on the assessment of treatment outcomes and the subsequent development of the periapical process according to three criteria: successful treatment, questionable treatment success, and treatment failure. These criteria are based on clinical and radiographic examinations of the patient over a 4-year period [18].

The American Association of Endodontists has adopted the following term for assessing the quality of endodontic treatment: "functional tooth," which includes such parameters as an asymptomatic tooth with no radiographic signs of periapical pathology and a functional tooth, and an "unhealed tooth," which is a nonfunctional tooth with inflammatory symptoms and radiographic signs of periapical pathology.

When comparing the results of various conservative periodontitis treatment methods, researchers require comparative criteria to establish statistically significant differences. Traditionally, clinical and radiographic studies have been used primarily as criteria for testing root canal obturation materials. Furthermore, they have been conducted over several years to assess recovery or further disease progression. The lack of standardization or harmonization of study results is a major obstacle to progress in the objective evaluation of clinical outcomes in the treatment of periodontal pathology [19]. This primarily concerns the assessment of the quality of endodontic treatment for teeth with compromised apical constriction.

Based on the above, we conclude that the search for new methods for objectively assessing the results of endodontic treatment remains relevant. The development of appropriate, accessible standards for assessing the quality of treatment will allow practitioners to objectively evaluate their work and, therefore, improve their skills in a timely manner.

Today, modern endodontics offers dentists a variety of dental treatment options. Today's clinicians must understand that endodontic treatment must have a favorable outcome. Therefore, this issue has medical and social significance.

**The objective of the study:** was to evaluate the effectiveness of treating teeth with periapical pathology based on clinical and radiographic examination methods, depending on the state of apical constriction, and to justify the choice of obturation material.

## 2. Material and Methods.

### 2.1 Clinical Study Objects.

The study involved 156 patients who treated 194 teeth (365 roots) (107 women and 49 men) aged from 20 to 60 years and older (average 47±5 years), with destructive forms of apical periodontitis in the acute stage. The study utilized a retrospective cohort study and a randomized cohort study. Patients were assigned to groups based on the type of permanent root canal filling materials used and the degree of apical constriction destruction. Long-term outcome studies were conducted over periods ranging from 6 months to 4 years. Patients were examined and treated at Donetsk State Healthcare Institution No. 1 and the Department of Orthopedic Dentistry at the Donetsk State Medical University of the Russian Ministry of Health. Patients were recruited from 2018 to 2021. Endodontic treatment was performed on participants diagnosed with ICD-10 codes K04.5–K04.8, K03.3 "Pathological tooth resorption" and K03.39 "Pathological tooth resorption, unspecified" (ICD-C), and the ICD-10 code "Diseases of the pulp and periapical tissues. Periodontitis. Acute chronic periodontitis of permanent teeth." All participants had no underlying medical conditions, no chronic erosive or ulcerative diseases of the oral mucosa, or moderate to severe periodontitis that could worsen dental or general health. A retrospective study was used, including an analysis of dental records (Form No. 043u) of patients with periapical lesions in permanent teeth treated with the study filling materials. In accordance with the study plan and an assessment of previously obtained laboratory and technical results (scanning electron microscopy and spectral analysis of the test materials), it was decided to evaluate and validate the use of ES in clinical practice based on a clinical and radiographic analysis, depending on clinical cases and the condition of the apical tissues. All participants were divided into three groups based on the RC obturation material used. For these purposes, widely used endodontic ESs belonging to various groups were used: Foredent, Sealapex, Trioxident. Foredent was used to fill the root canals of 82 teeth (42.27%), Sealapex was used to fill 94 teeth (48.45%), and Trioxident was used to fill 18 teeth (9.27%). This was also due to the state of the apical constriction of the treated teeth. Trioxident was not used to fill root canals of teeth with preserved apical constriction due to the difficulty of inserting it into these root canals. However, it was used in 40.74% of cases of teeth with destroyed apical constriction.

Patients were also divided into three groups based on the degree of apical constriction destruction. After determining the degree of destruction, the doctor decided on the type of filling material to use for permanent root canal restoration

### 2.2 Radiographic examination of periapical pathology.

All participants underwent radiographic examination, including examination with a 5D2 intraoral dental X-ray diagnostic unit, a SOPIX 2 radiovisiograph (Acteon Group France), and CBCT using a standard technique: before treatment, during treatment, after filling the periapical canal, and at late stages after completion of treatment to assess the dynamics of changes in the periodontium. Radiographic images were analyzed using existing methods [20]. Dental radiographs taken with the radiovisiograph were examined using a computer magnification program. Based on the radiographic examination, all participants were divided into three groups based on the state of apical constriction, which corresponded to the radiographic standards of M. Laux (2000) [21].

### 2.3 Periapical index for assessing the quality of endodontic treatment of destructive periodontitis.

To compare and contrast the study data, we used the Periapical Index (PAI) [22, 23] described by D. Orstavik et al. (1986) (Table 1) and an assessment of the change in lesion area, which was calculated using the irregular circle formula ($S = \pi \times r1 \times r2$), where S is the area, $\pi$ is 3.14, r1 is the radius of the smallest diameter, and r2 is the radius of the largest diameter. The healing dynamics of the inflammatory lesion were assessed as satisfactory (with a reduction in the lesion size by more than 50% over six months to a year) and good (with complete bone tissue restoration as assessed by radiographic examination).

**Table 1** Interpretation of the Periapical Index (PAI).

| PAI Points | Description |
|---|---|
| 1 | Normal apical periodontium. |
| 2 | Minor bone structural changes indicative of apical periodontitis, but not typical of it. |
| 3 | Bone loss and structural changes with some mineral loss, characteristic of apical periodontitis. |
| 4 | Clearly visible radiolucency. |
| 5 | Reinflation with radical spread of bone structural changes. |

To improve the effectiveness of endodontic treatment, we developed a periapical index for assessing the quality of endodontic treatment for teeth with destructive forms of periodontitis (Table 2).

**Table 2** Periapical Index for Assessing the Quality of Endodontic Treatment for Destructive Forms of Periodontitis.

| Treatment | Clinical criteria for treatment | Radiographic criteria for treatment | Points |
|---|---|---|---|
| Successful treatment | No clinical signs of inflammation in the periodontal tissues. Tooth mobility is normal. Tooth function is preserved. | 1.1. Within 4 years after endodontic treatment, the bone structure is homogeneous. The periapical space is 0.5-1 mm wide. The cementodentinal junction is formed in the apical area. The root canal is tightly obturated throughout its entire length. | 9 |
| | | 1.2. Within 1 year after treatment, restoration of a homogeneous bone structure is observed. The periapical space is 1-2 mm wide. The root canal is tightly obturated. Signs of cementodentinal junction formation are present. | 8 |
| | | 1.3. Within 6 months after endodontic treatment, restoration of the bone structure by 1/2 to 2/3 of the size of a large periapical lesion is observed. The periapical space is 1-2 mm wide within 6 months after treatment. The cementodentinal junction is formed in the apical area. The root canal is tightly obturated. | 7 |

| | | | |
|---|---|---|---|
| Questionable result | Post-obturation pain persists for the first 5-7 days. After treatment, discomfort with chewing, percussion, and palpation may persist for a month or more. Tooth mobility is normal. One exacerbation is possible within 6 months after endodontic treatment. | 2.1. Partial restoration of the periapical bone destruction focus within 1 year. Restoration of the destruction focus within 2 years. The periapical space width is 1-2 mm. No signs of cementodentinal junction formation. The root canal is tightly obturated.<br><br>2.2. The size of the bone destruction focus does not decrease within 6 months after completion of endodontic treatment. Restoration of the destruction focus within 2 years. The periodontal gap is uneven in the periapical area. No signs of cementodentinal junction formation. The root canal is tightly obturated.<br><br>2.3. Restoration of the destruction focus within 2-4 years. The destruction focus has decreased by no more than 1/3-1/2 of its original size. No signs of cementodentinal junction formation. In case of improper endodontic treatment of the root canal and its obturation. | 6<br><br>5<br><br>4 |

| | | | |
|---|---|---|---|
| | | 2.4. Reduction but persistence of bone destruction in the periapical lesion of any size for up to 4 years. Cementodentinal junction (CDJ) is not formed. In case of improper endodontic treatment and obturation of the root canal. | 3 |
| Unsuccessfu l treatment | Pain persists during treatment. Post-obturator pain persists for the first 14 days. Symptoms of inflammation include pain on percussion and palpation in the root apex area. Possible signs include a fistula, hyperemia of the alveolar mucosa, and abnormal tooth mobility for up to 1 year after endodontic treatment. | 3.1. No changes in the periapical lesion for more than 4 years. No signs of cementodentinal junction formation. In case of improper endodontic treatment and obturation of the root canal. | 2 |
| | | 3.2. The bone destruction lesion is enlarged. No signs of cementodentinal junction formation. In case of improper endodontic treatment and obturation of the root canal. Signs of resorption of the filling material in the canal are possible. | 1 |

**2.4 Statistical Methods.**

Statistical processing of the obtained results was performed in accordance with the study's objectives and tasks using mathematical statistical methods. A personal computer and Microsoft Excel (Microsoft Corporation, Tulsa, USA) were used. The results were analyzed using the Statistica 6.0 software package (IBM® SPSS® Corporation, Chicago, USA). Statistical analysis was performed using the Student's t-test for unrelated and independent groups. It was used to statistically test hypotheses based on the Student's t-test. The t-test is used to test the equality of mean values in two samples. The Kruskal-Wallis rank test was used when qualitative differences between the indicators of use of the selected medications were needed. This procedure is an analysis of variance based on ranks. Post hoc comparisons were performed using Mann-Whitney analysis to assess differences between two independent samples in the level of any quantitatively altered trait.

**2.5 Traditional Treatment Methods**

Traditional endodontic treatment methods are described based on the unified clinical protocol "Diseases of the Pulp and Periapical Tissues. Periodontitis. Acute Chronic Periodontitis of Permanent Teeth," adopted in the Russian Federation. Treatment principles for patients with periodontitis involve the simultaneous solution of several objectives:

1. stopping the further progression of the pathological process;
2. preserving and restoring the anatomical shape of the affected tooth and the functional capacity of the entire dentoalveolar system;
3. restoring the aesthetic appearance of the dentition.

If conservative treatment is unsuccessful or impossible, conservative-surgical or surgical treatment methods are considered: apical resection, hemisection, coronal-radicular separation, or tooth extraction. The following factors influence the choice of treatment strategy:
1. The anatomical structure of the tooth (significantly curved or atypical roots pose a significant problem).
2. The pathological condition of the tooth (severe root canal obliteration, internal or external root canal resorption, horizontal and vertical root fractures).
3. The consequences of previous interventions on the tooth.
4. Isolation, access, and feasibility of treatment (the ability to adequately isolate the treatment area, the patient's mouth opening, and any associated pathologies).
5. The functional value of the tooth.
6. The possibility of subsequent restoration of the anatomical shape of the crown.

The choice of periodontitis treatment method depends on the clinical presentation, manifestations and symptoms, and diagnosis, and can range from dynamic observation to tooth extraction.

According to local protocols, the treatment of teeth with periodontitis in the acute stage includes the following mandatory measures:

<u>1 visit:</u>
1. Antiseptic treatment of the oral cavity (rinsing).
2. Pain relief (if necessary).
3. Cleaning the tooth surface from plaque and deposits.
4. Preparation of altered tooth tissues; in case of retreatment – complete removal of the coronal filling; in case of an intact crown – trepanation; opening the tooth cavity; creating access to the RC; in case of retreatment – complete removal of the root filling.
5. Determining the working length of the RC.
6. Instrumental and medicinal treatment of the root canal; in the presence of exudate – widening the apical foramen to 25 according to ISO. According to standardized clinical protocols, medicinal treatment of root canals includes antiseptic preparations: antiseptic solutions (1% chlorhexidine solution, 1% iodinol solution, 3% hydrogen peroxide solution, etc.); Quaternary ammonium compounds (0.5%-1% ethonium solution, 1% benzalkonium chloride solution, 0.15% decamethoxin solution); phenolic compounds (5% phenol solution, 1% camphor-paramonochlorophenol solution and their combinations); nitrofurans, antibacterial drugs; immobilized drugs; sorbents; anti-inflammatory drugs, etc.
7. The tooth is left open for 2-5 days.
8. The doctor may choose a treatment strategy involving leaving a calcium-containing preparation in the RC during the first visit or an sorbent under a sealed temporary filling.
9. Prescribed (if necessary): painkillers, antihistamines, anti-inflammatory drugs; warm rinses with soda or saline solution; cotton balls in the cavity during meals. In the case of an acute process complicated by periostitis, it is recommended to make an incision along the transitional fold in the area of the causative tooth.

<u>2nd visit:</u>
1. Antiseptic treatment of the oral cavity (antiseptic rinses).
2. Repeated instrumental treatment of the canal to its full working length using appropriately sized endodontic instruments.
3. Medication with the insertion of a cotton swab soaked in an antiseptic solution or a temporary therapeutic filling paste into the canal.
4. Temporary covering of the tooth for 2 to 7 days with a semi-hermetic or hermetic dressing (depending on the presence or absence of a small amount of serous exudate in the canal).

<u>3rd visit:</u>
1. Antiseptic treatment of the oral cavity (antiseptic rinses).

2. Removal of the temporary dressing.
3. Removal of the temporary therapeutic paste or cotton swab.
4. Final instrumental and medicinal treatment of the canal.
5. Permanent filling of the canal, performed using one of the two protocols below: with cement or paste (**Table 3**), or using a single gutta-percha pin with lateral condensation (**Table 4**)."
6. X-ray monitoring of endodontic treatment.
7. If indicated, temporary filling of the tooth for 1-3 days or placement of a permanent filling.

**Table 3: Root Canal Filling Algorithm with Cement and Pastes**

| | Stages | Contents |
|---|---|---|
| 1. | Preparing the necessary instruments | Lay the root canal needles, reamers, and canal filler on a glass plate. Place the stoppers at the working length of the canal. Wrap cotton swabs around the root canal needles with the cut ends (for filling with pastes). When filling with cement, moisten the needles and canal filler with alcohol and dip them in the powdered material (to prevent sticking). |
| 2. | Preparing the canal for filling | Rinse the canal with an antiseptic; dry thoroughly using cotton swabs or paper points; lubricate the root canal with the liquid in which the paste or cement is mixed (this will ensure easy movement of the endodontic sealant to the apical opening). |
| 3. | Mixing the filling material | Conduct in accordance with the methodology adopted for each material. |
| 4. | Root canal filling | Immerse the canal filler in the filling material, insert it into the root canal orifice and advance it vigorously towards the apex along the entire working length of the canal; turn on the drill at low speed (100-120 rpm) for 2-3 seconds; after completing the filling, remove the canal filler from the canal and then turn off the drill; repeat the procedure 2-3 times until the canal is completely obturation. |
| 5. | Final condensation of the material | Excess filling material accumulating above the mouth should be pushed into the canal with force using a cotton ball (for pastes), a probe or a plugger (for cements). |

**Table 4: Root canal filling algorithm using a single pin and lateral condensation with cold gutta-percha**

| | Stages | Contents |
|---|---|---|
| 1. | Determining the size of the spreader | Select a spreader of the same size as the last instrument (master file) or one size larger to avoid extending beyond the apical opening; use a stopper to fix the length 1-2 mm shorter than the working length of the canal. |

| | | |
|---|---|---|
| 2. | Determining the size of the master pin | Select a pin equal in size to the last instrument used at the root apex; disinfect the pin for 5 minutes in a 5.25% NaOCl solution, a 3% hydrogen peroxide solution, or a 2% chlorhexidine solution. |
| 3. | Pin fit: visual test | Using pliers, mark a length on the pin that is 1 mm shorter than the prepared (working) length of the canal; insert the pin into the canal until the pliers touch the corresponding outer surface of the tooth (a 1 mm margin allows for condensation in the apical direction without extending beyond the apex). |
| 4. | Drying the canal | Dry the canal using paper pins (select one size smaller than the last instrument). |
| 5. | Application of sealer into the canal using a canal filler | Dip the root canal filler into the sealer, insert it into the root canal, and carefully advance it toward the apex to the full working length; turn on the drill at low speed (100-120 rpm) for 2-3 seconds; remove the root canal filler from the canal, and then turn off the drill. |
| 6. | Insertion of the main pin | Lubricate the pin with sealer and slowly insert it into the canal, leaving 1 mm before the apical opening; use a hot excavator or other instrument to remove excess pin to the level of the neck. |
| 7. | Insertion of auxiliary pins (lateral condensation method) | Insert the spreader to its full depth and leave it in the canal for 1 min. (to ensure lateral and partially apical condensation) remove the spreader from the canal with a rotational motion; immediately insert the first auxiliary pin, having previously lubricated it with sealer; insert the spreader and perform lateral condensation of the material; remove the spreader from the canal with a rotational motion and insert another auxiliary pin (the procedure lasts until the canal is completely obturation) remove excess gutta-percha and sealer from the crown; perform vertical condensation with a plugger. |

4th visit:
1. Antiseptic treatment of the oral cavity (antiseptic rinses).
2. Removal of the temporary filling.
3. Placement of an insulating liner.
4. Placement of a permanent filling made of glass ionomer cement, photo- or chemical composites.
5. Occlusion correction, grinding and polishing of the filling.
6. If the IROPZ is >0.4-0.8, referral for orthopedic treatment.
7. If surgery is necessary, the patient is referred to an oral surgeon.

The above endodontic treatment plan does not detail recommendations regarding the treatment strategy for teeth with chronic apical periodontitis in the acute stage with varying degrees of apical constriction. The problem of opening the tooth without subsequent placement of a temporary sealed restoration during the first visit also remains unresolved. Therefore, we have developed a method for endodontic treatment of teeth with this condition.

**2.6 Proposed Treatment Method**

This treatment regimen is aimed at treating teeth with acute forms of chronic periodontitis with varying degrees of apical constriction destruction. Protocols for this study were developed before treatment began, and all data are tabulated.

The protocol recorded primary and clinical factors.

Primary factors included:
1. Clinical diagnosis at initial examination.
2. Periapical lesion size in millimeters, measured using intraoral X-ray or computed tomography.
3. Presence or absence of previous conservative endodontic treatment.

Clinical factors included:
1. Presence or absence of previously installed restoration, tooth seal.
2. Working length of the root canal.
3. Condition of apical constriction.
4. Selection of filling material for permanent obturation.

Based on the examination data, the patient was diagnosed, treated, and the quality of the treatment was monitored.

Endodontic treatment was performed according to a standardized protocol of instrumental and medicinal preparation, with mandatory isolation of the working field using a rubber dam.

Normal physiological (small opening) is 0.1-0.2 mm, which corresponds to a 10-20 file. In long-term inflammatory processes, the state of the apical constriction can change and the cementodentinal junction can be disrupted. Therefore, it was decided to divide the patients into three groups: those with preserved constriction, those with partially destroyed constriction, and those with severely destroyed constriction, which met the radiographic criteria of M. Laux (2000):
1. Category of teeth without signs of resorption.
2. Category of teeth with signs of moderate resorption, which was visualized on radiographs as a blurred, uneven root contour.
3. A category of teeth with signs of severe resorption, visualized on radiographs as distinct radiolucent depressions or shortening of the root tip.

According to our radiographic examinations of 194 teeth with destructive forms of apical periodontitis, root apex resorption was detected in only 47 cases, representing 24.22%.

<u>Visit 1:</u>

1. Antiseptic treatment of the oral cavity (antiseptic rinses).

2. Cleaning the tooth surface of plaque and deposits.

3. Isolation of the working field with a rubber dam.

4. Necrotomy, medicated treatment of the carious cavity with 5.2% NaOCl, access to the root canals.

5. Primary treatment of the coronal and middle thirds was performed after preliminary scouting of 2/3 of the root canal to evacuate putrid decay and prevent blockage of the apical third by dentin filings and infection of the periapical tissues.

6. After cleaning and removal of obstructions in the coronal portion, an "apical third reconnaissance" was performed, followed by determination of the working length. For this, the stop was set to a mark

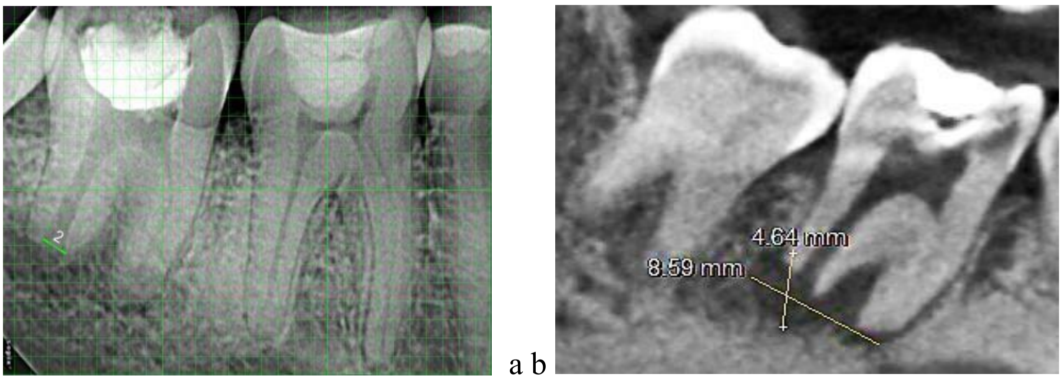
corresponding to the average value of the estimated length of the tooth canal being treated. Deviations of up to 2 mm in either direction are acceptable, as This may be due to the individual characteristics of the tooth in this group. It is believed that in cases of root apex resorption, root canal preparation for filling should be completed 0.5 mm short of the radiographic apex, which is 1.5 mm in total, and in cases of extensive resorption, 2 mm or more short of the radiographic apex. In the presence of exudate, the apical foramen was widened to ISO 25.

7. Before commencing instrumentation of the RC, the approximate working length of the canal was determined. Histologically, working length is the distance from the point marked on the crown to the cementodentinal junction, in close proximity to the apical constriction. According to the American Association of Endodontists, the working length of the canal is the distance from the coronal reference point to the point at which canal preparation and obturation should be completed. D. Ricucci (1998) defined apical constriction as the narrowest portion of the root canal with the smallest diameter of the blood supply, when preparation to this level results in the most optimal histological conditions for healing.

8. To determine the endpoint of chemomechanical treatment, the primary (electronic apex locator) and additional (radiographic, periodontal sensitivity, tactile, and paper point) methods were used.

9. To determine the state of apical constriction, a 15.02 hand K-file was inserted into the pre-dried canal using a reciprocating and rotating motion. If apical movement of the instrument was obstructed and the apex locator signaled apical constriction, an X-ray examination was performed, after which the instrument was removed and the working length was fixed using an endodontic ruler. This condition of the physiological foramen was classified as GROUP I, with preserved constriction. If no resistance to instrument advancement was observed during sequential insertion of the 15.02 and 20.02 K-files and the apex locator signaled the instrument's exit beyond the apex, hand K-files 25.02–40.02 were used sequentially. If an obstruction to apical movement was felt and the apex locator signal appeared, an X-ray examination was performed, then the instrument was removed, and the working length was recorded. This condition of the physiological foramen was classified as GROUP II, with partially disrupted constriction.

10. No further file enlargement was performed if there was no resistance. A 40.02 K-file was inserted until the apex locator signaled that the instrument had exited the root canal. The file was then advanced coronally by 0.5-1 mm until a 0.2-0.7 mm mark appeared on the apex locator screen. An X-ray was then taken. The file was then removed to establish the working length. These teeth were classified as GROUP THREE, with severely compromised apical constriction (Figure 1).




a b

**Figure 1.** Radiovisiogram of tooth 47 (a). CBCT section of tooth 47 (b).

This radiograph of tooth 47, taken with a SOPIX 2 radiovisiograph (Acteon Group France), shows oval-shaped bone destruction with fuzzy contours in the root area. The radiovisiograph's measuring scale was also used to measure the apical foramen (Figure 1.a). The CBCT section of tooth 47 additionally measures bone destruction in two planes (Figure 1.b).

Teeth with radiographically detectable root resorption pose a particular challenge for treatment. This indicates extensive destruction in the root apex. In such cases, it may be necessary to preliminarily measure the apical foramen using a radiovisiograph scale or a CT scan. An example of one possible error in determining the working length of the canal is shown in Figure 2.

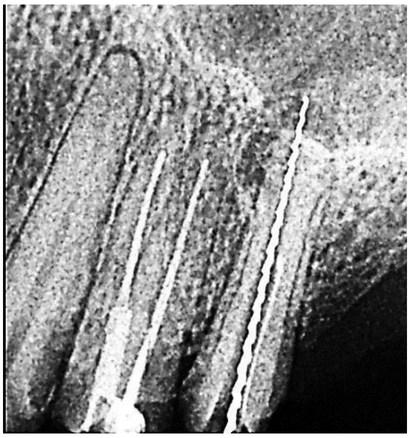


**Figure 2.** X-ray of tooth #25 with a 35.02 K-reamer inserted into the root canal.

This X-ray shows a tooth with chronic apical periodontitis in the acute stage. The periodontal ligament space is dilated. A well-defined, rounded, radiolucent area is visible in the apex, surrounded by a zone of perifocal osteosclerosis. There is erosion of the root apex.

Using the tactile and periodontal sensitivity methods, the working length was determined incorrectly. A 35.02 K-reamer was inserted into the root canal, extending the tip of the instrument 2 mm beyond the root canal into the periapical tissues. To verify the apical foramen size, in addition to using conical gutta-percha points, a radiopaque temporary filling material based on calcium hydroxide can be used.

11. To obtain more accurate data when verifying the apical foramen size in the absence of a radiovisiograph and CBCT (Figure 3a), it was proposed to use a method for calculating the apical foramen size using a gutta-percha point.

12. For this purpose, 25.06 gutta-percha points were used. Scissors were used to shorten the gutta-percha point in 1 mm increments until the stop at the apex was reached, as shown in Figure 3b.

To determine the apical foramen diameter, a calculation formula was developed and proposed:

$$Ap1 + K * L = Ap2 \quad (1)$$

where Ap1 is the initial size of the gutta-percha point (25 according to ISO);

K is the taper value of the gutta-percha point (6);

L is the length by which the gutta-percha point is shortened;

Ap2 is the final size of the gutta-percha point.

Reducing the point size by 7 mm using the formula yields 67, which corresponds to an ISO file size of 65 or 0.65 mm: 25 + 6 * 7 = 67.

After determining the apical stop with a calibrated gutta-percha point, a radiographic examination was performed to more accurately determine the working length of the canal. The canal was then instrumented and chemically treated, and then filled with a calcium-containing non-hardening sealer to the full working length (Figure 3c). There was no need to use machine files larger than 25.06.

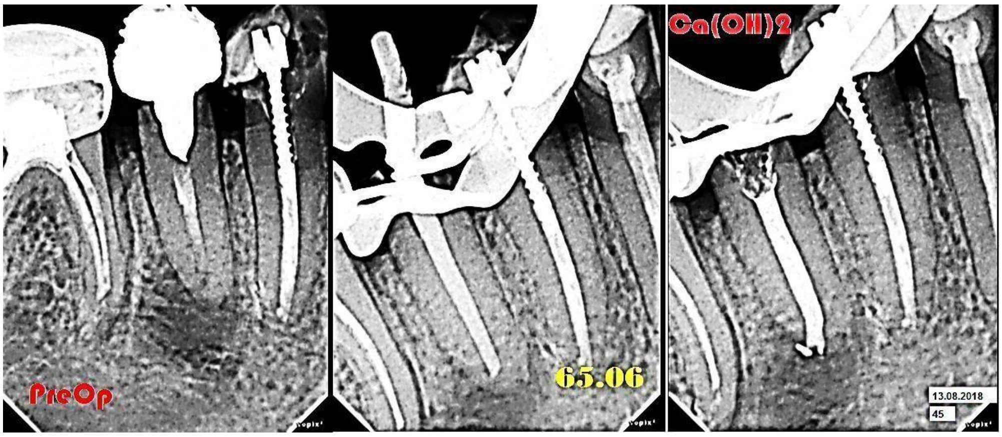



**Figure 3.** Radiographs of tooth 45: initial situation (a); image with a calibrated gutta-percha pin of 06 taper (b); image with a temporary calcium-containing material in the root canal (c).

13. For antiseptic treatment of the CC, as suggested in the Clinical Protocols, a 5.2% NaOCl solution from the Russian company TechnoDent was used according to TU 9391-001-67200978-2010. Combined treatment was carried out with EDTA-based preparations "EndoZhi No. 2" from the company VladMiVa according to TU 9391-041-45814830-2001.

14. After antiseptic treatment of the CC, they were filled with Apexdent from the company VladMiVa TU 9391-071-45814830-2001, containing calcium hydroxide, which creates a high pH environment (pH 12.5). Apexdent was chosen because It has previously been shown that the use of calcium hydroxide-containing preparations in the treatment of destructive forms of periodontitis reduces the number of bacteria in the oral cavity.

15. The tooth cavity was hermetically sealed with Unitsem (VladMiVa), ISO 10993-11-2011, GOST R 52770-2007. Nonsteroidal anti-inflammatory drugs, antibiotics, sulfonamides, antihistamines, or physical therapy were not prescribed.

<u>Visit 2, two weeks later, if there are no signs of inflammation:</u>

1. Antiseptic treatment of the oral cavity.

2. Isolation of the working field and creation of access to the root canal.

3. Filling the root canal using one or another of the studied endo-sealers, while repeating the root canal cleaning protocol.

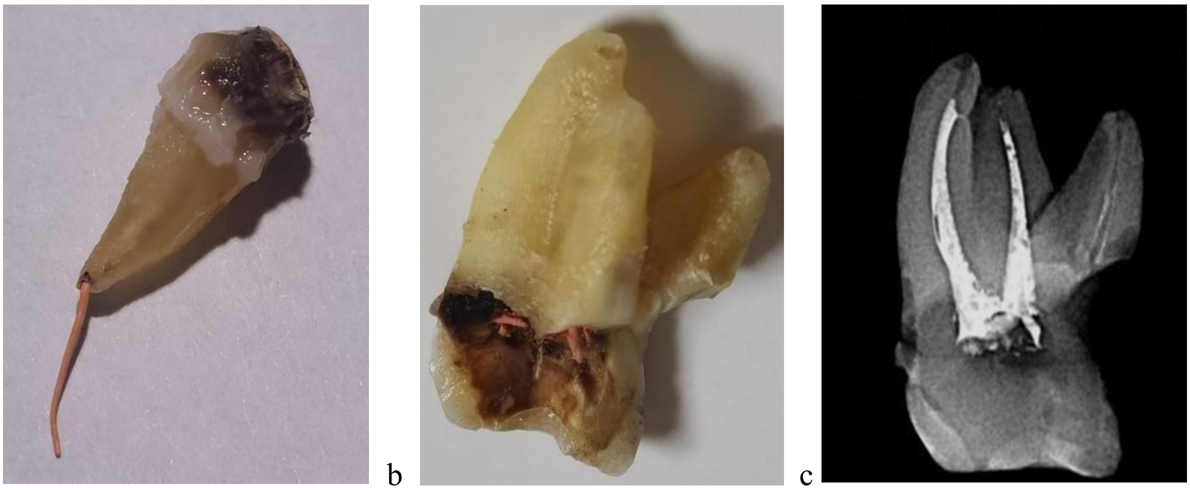
4. According to indications, temporary closing of the tooth for 1-3 days or placement of a permanent filling.

Treatment was continued until a positive clinical result was achieved: no exacerbation of the inflammatory process was observed, the tooth withstood functional load, and the condition of the bone tissue in the periapical region indicated stabilization of the process.

**Results.**

**Analysis of long-term clinical outcomes of endodontic treatment.**
**3.1 Complications of treatment of teeth with periapical pathology.**

While conducting clinical observations of complications following treatment of teeth with periapical pathology 2-3 years earlier, we discovered that in some teeth, gutta-percha pins had been extruded into the periodontal space through the wide apical foramen, as clearly shown in Figure 4 (a). In one case, gutta-percha pins were not extruded beyond the apical foramina of a multi-rooted tooth, but poor-quality filling of the RC or resorption of the ES led to root tissue resorption (Figure 4 b). These filling issues and the consequences of poor treatment were diagnosed using X-rays (Figure 4 c).



a b c

**Figure 4.** Photo of tooth 35, extracted 2 years after treatment. Gutta-percha pin removed through the destroyed apical constriction (a). Horizontal and vertical root resorption of tooth 17 2 years after filling. Thinning of the buccal root wall along the entire length, shortening of the roots along the length, wide apical foramina (b). Radiograph of tooth 17 (c).

Radiographic examination (Figure 4 c) revealed vertical and horizontal root resorption with a porous structure in the buccal roots. The tissues of these roots exhibit increased translucency. In the apical regions of the roots, uneven surfaces of uneven width, with unclear contours, and increased translucency are observed. Shadows are visible within the lumens of the RC as heterogeneous, linear darkened areas with unclear contours, corresponding in density and configuration to fragments of ES. This may indicate resorption of ES from the RC over time.

### 3.2 Results of treatment of teeth with periapical pathology using Foredent.

Based on clinical and radiographic examination, the first group included 66 participants who had 82 (42.02%) teeth treated using Foredent as an ES. In this group of participants, exacerbations of chronic periodontitis were more common in individuals over 60 years of age. A total of 44 (53.65%) single-rooted, 15 (18.29%) two-rooted, and 23 (28.04%) three-rooted teeth were filled.

As the first clinical example, the radiographic results of treatment of tooth 25 with root apex resorption are presented (Figure 5). The patient presented to the dentist complaining of pain in the area of tooth 25, which had previously undergone endodontic treatment. The radiograph reveals a bright, radiopaque shadow on the crown of the tooth, corresponding to the metal framework of the crown. Partial obturation of the RC manifests as a non-uniform radiographic shadow in the middle third of the RC, a narrow band of darkening along the distal surface of the canal, and in the apical third. The periodontal ligament space is dilated and appears as a clear band between the root surface and the compact layer of the socket. In the periapical region of the root of tooth 25, a focus of alveolar bone destruction with fuzzy oval contours and a high degree of cancellous tissue lucency is observed, extending medially and surrounded by an uneven zone of perifocal osteosclerosis. Apical resorption is visible as a radiolucent depression on the medial surface (Figure 5 a). CBCT sections show bone destruction in the apical region of the tooth as an area of increased transparency, uneven in width, and fuzzy oval contours (Figure 5 b).

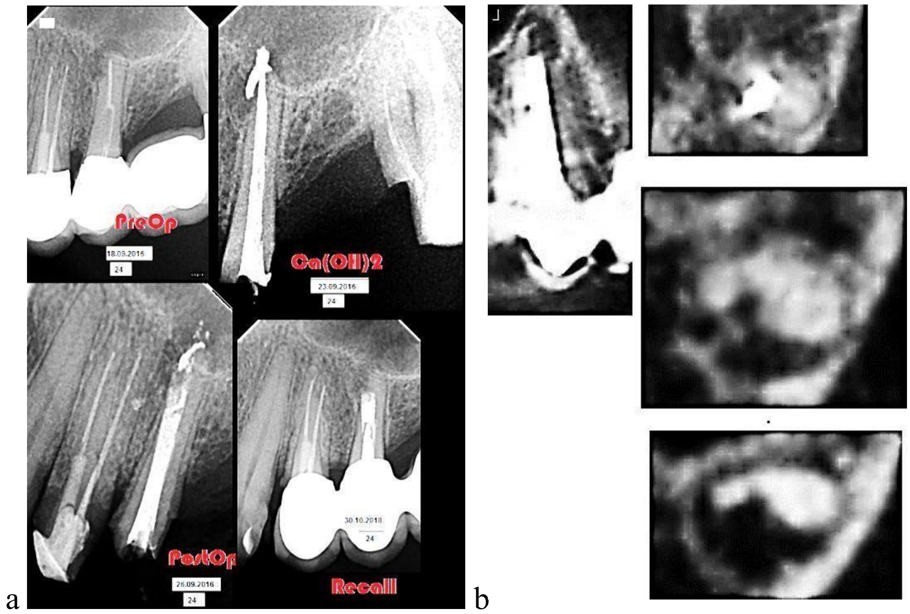



**Figure 5.** Radiographs of tooth 25: diagnostic, at the time of treatment, and 25 months after completion of treatment (a); diagnostic CBCT of tooth 25 (b)

Following treatment, the RC was filled with Foredent. Three days later, an anchor pin was placed in the canal using Unitsem. Six months after treatment, the patient returned for a routine examination. She had no complaints. Objectively: the tooth was covered with an artificial crown as an abutment for a fixed bridge. The control radiograph shows a bright shadow in the RC, corresponding in radiopacity to the contours of the metal pin. The RC walls are tightly obturated. Apical root resorption is present as a radiolucent depression on the medial surface. The periodontal ligament space is widened. Increased radiolucency of bone tissue in the periapical region.

A year later, the patient returned to the dentist complaining of toothache in the upper left jaw, which worsened when biting down on the tooth. A radiograph revealed a bright shadow in the RC, corresponding in radiopacity to the contours of the metal post. The filling material was not visible around the apex of the post. The RC walls were tightly obturated. Resorption of the filling material was observed in the apical third of the root. Apical root resorption was observed. The periodontal ligament space was dilated. A lesion of bone tissue with ill-defined contours and a slight degree of lucency of the spongy bone tissue was observed in the periapical region, extending medially. The lesion was surrounded by a zone of perifocal osteosclerosis in the form of a uniform band (Figure 6).

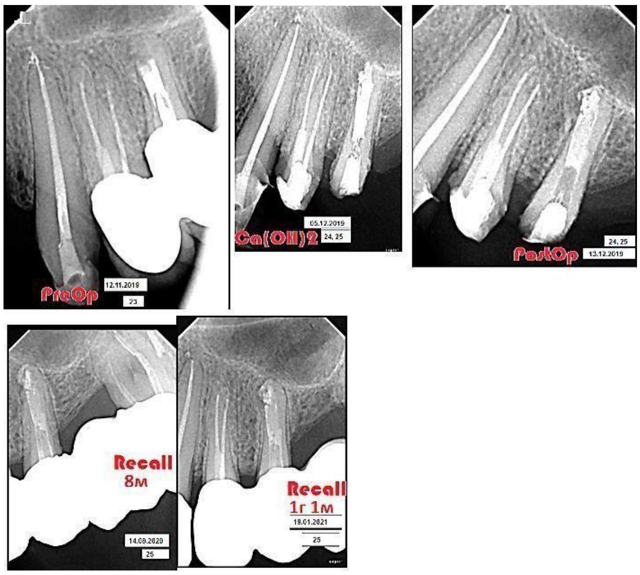



**Figure 6.** Radiographs of tooth 25: 3 years and 2 months after completion of treatment; during retreatment; 8 months after completion of treatment; 13 months after completion of treatment.

Following the treatment, the RC was filled using Trioxident. The patient has had no complaints in the five years since the Trioxident treatment of tooth 25.

### 3.3 Results of treatment of teeth with periapical pathology using Sealapex with gutta-percha pins using the lateral condensation method.

Following clinical and radiographic examination, the second group included 72 participants who had treated 94 teeth using Sealapex ES with gutta-percha pins using the lateral condensation method. In this group, exacerbations of chronic periodontitis were more common in individuals over 50 years of age. Among the treated teeth, 64 teeth with preserved apical constriction (53.78%), 21 (43.75%) with partially destroyed constriction, and 9 (33.33%) with destroyed constriction were filled. As a second clinical example, radiographic results of the treatment of tooth 37 with partially destroyed apical constriction are presented (Figure 7).

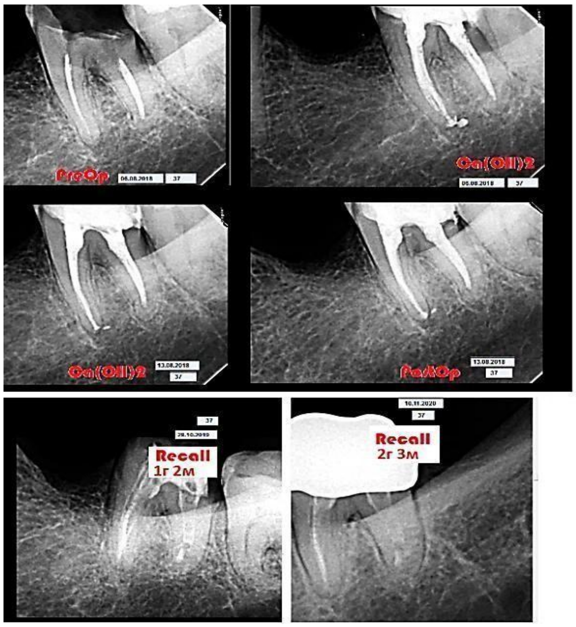



**Figure 7.** Radiographs of tooth 37: diagnostic; during treatment with a calcium-containing material for temporary root canal obturation; after permanent root canal filling; 14 months after completion of treatment; 2 years and 3 months after completion of treatment

After 14 months, radiographic imaging revealed that the root canals were tightly obturated throughout their entire length. Shadows in the RC were visible as linear clear areas with clear contours, corresponding in density and configuration to fiberglass posts. The periodontal ligament space was within normal physiological limits. There was no bone destruction. This trend continued.

### 3.4 Results of treatment of teeth with periapical pathology using Trioxident.

The third group included 18 participants who had 18 teeth (37 roots) treated with Trioxident. Five of these teeth had single roots, eight had two roots, and six had three roots. The patients were primarily aged 20-30 years. In two cases, only the roots in the third group, those with destroyed apical constriction, were filled with Trioxident. The other two roots were filled with Sealapex and gutta-percha pins using the lateral condensation method.

As a third clinical example, we present radiographs of tooth 47 with destructive periodontitis and severely destroyed apical constriction. The radiograph of tooth 47 shows a shadow with jagged edges at the periphery in the coronal portion, corresponding in radiopacity to the contours of the filling material. The periodontal ligament space is expanded on the distal root surfaces. The integrity of the alveolar compact plate is compromised. Resorption of the distal root apex appears as a uniform radiolucency with rough outlines of a truncated cone. Shortening of the distal root. Using a radiovisiograph scale, the apical foramen size was determined to be 2 mm. A focus of bone tissue destruction in the root apex area has unclear contours, an oval shape, increased radiolucency, and partially preserved bone pattern. CBCT of tooth 47 shows increased radiolucency of bone tissue in the root area, encompassing half the length of the interradicular septum and extending the entire length of the medial root to the border of the alveolar crest. Radiolucency of bone tissue in the medial root area extends to the lower border of the jaw with unclear contours. Radiolucency measures 8.59 x 4.64 mm. Root apex resorption is characterized by uniform radiolucency with rough truncated cone-shaped contours (Figure 8).


**Figure 8.** Diagnostic CBCT of tooth 47 (a). Radiographs of tooth 37: diagnostic; during treatment; control of CBCT obturation RC Trioxident; 6 months after treatment; 1.5 years after treatment.

The patient returned for radiographic follow-up appointments at 6 months and 1.5 years. On the control radiograph of tooth 47, shadows with clear contours in the form of continuous linear structures are determined throughout the lumen of the RC. The periodontal space is widened approximately 1 mm in the periapical region of the distal root. The periodontal space is not widened in the area of the mesial roots. The bone structure is normal.

### 3.4 Periapical quality index for endodontic treatment of destructive periodontitis.

Long-term clinical outcomes of endodontic treatment were assessed at 6 months, 1 year, 2, 3, and 4 years. Complaints were collected, and the nature of subjective sensations was determined throughout the observation period. A visual examination of the patient was then performed, including an external examination, an examination of the oral cavity, and the affected tooth. A radiographic diagnosis was then performed. All data were recorded in the dental patient's medical record. To assess the dynamics of radiographic parameters after treatment in patients with destructive forms of chronic apical periodontitis, PAI values were assessed and changes in the area of the destructive lesion (mm2) were calculated. Because severe root resorption with destruction of apical constriction develops over a long period of time, the lesion size could reach 1.5-2 cm, averaging 9.0 ± 2.3 mm. No correlation was found between lesion size and the degree of resorption in teeth with preserved and partially destroyed constriction. The average lesion size was 6.5 ± 2.5 mm. Therefore, the lesion size was assigned a weighting of 100%, and its change from the initial size over a period of up to one year was monitored. The PAI value was estimated as the mean for each group (Table 5).

**Table 5** Remote results of endodontic treatment of teeth depending on the state of apical constriction and the selected endodontic sealant

| | Groups | | |
|---|---|---|---|
| | Preserved constriction (I) | Partially destroyed (II) | Destroyed constriction (III) |

| | Foredent | Sealapex +gutta-percha pins | Foredent | Sealapex +gutta-percha pins | Trioxident | Foredent | Sealapex +gutta-percha pins | Trioxident |
|---|---|---|---|---|---|---|---|---|
| Number of teeth | 55 | 64 | 20 | 21 | 7 | 7 | 9 | 11 |
| Treatment success rate | 85.4% | 96.87% | 61 % | 95.2 % | 92 % | 47.14% | 85 % | 91 % |
| PAI value and lesion area before treatment | | | | | | | | |
| Average PAI value | 3.65± 0.13 | 3.85 ± 0.2 | 3.75± 0.13 | 3.69 ± 0.15 | 3.9 ± 0.24 | 4.14 ± 0,12 | 4± 0.2 | 3.9 ± 0.18 |
| Area of the hearth (%) | 100% | | | | | | | |
| Six months after treatment | | | | | | | | |
| Average PAI value | 3.1 ± 0.16 | 2.85 ± 0.2 | 3.15± 0.15 | 2.6± 0.1 | 2.6 ± 0.24 | 3.6± 0.12 | 2.7± 0.2 | 2.6 ± 0.18 |
| Area of the hearth (%) | 63 % | 50 % | 73 % | 65 % | 69 % | 80 % | 66 % | 53 % |
| One year after treatment | | | | | | | | |
| Average PAI value | 2.9 ± 0.18 | 2.1± 0.16 | 2.9 ± 0.15 | 1.8± 0.1 | 1.9 ± 0.2 | 3.1± 0.2 | 2.1± 0.1 | 1,9 ± 0,18 |
| Area of the hearth (%) | 32 % | 10% | 54 % | 12% | 14 % | 63% | 29% | 18 % |

Currently, there are no uniform criteria for assessing the quality of endodontic treatment. Existing criteria are not entirely suitable for assessing the quality of treatment for teeth with destructive forms of periodontitis and destroyed apical constriction.

To improve the effectiveness of endodontic treatment, we developed and proposed criteria for assessing the quality of endodontic treatment for teeth with destructive forms of periodontitis. Endodontic treatment was divided into three groups: unsuccessful treatment, questionable outcome, and successful treatment. Both clinical and radiographic signs served as criteria for treatment success. Radiographic assessment included not only the quality of the RC obturation but also dynamic changes in the bone tissue, periodontium, and root.

Of the 82 teeth filled with Foredent, 56 teeth (68.29%) were reexamined 89 times over periods ranging from 6 months to 4 years. Seven teeth were examined in the first six months, 43 teeth within one year, 27 teeth after two years, 9 teeth after three years, and 3 teeth after four years. During this time, the periapical index of some teeth changed. However, overall, the picture emerged of relatively successful endodontic treatment.

Of the 94 teeth filled with Sealapex and gutta-percha pins, 37 teeth (39.36%) were re-examined. Seven teeth were examined after 6 months, 22 teeth after 1 year, and 8 teeth after 2 years. Seven teeth (18.91%) met the criteria of 7 points. They were re-examined after 6 months and in all cases a decrease in the focus of bone tissue destruction was noted. This category included teeth from resorption groups I and II, but with bone tissue destruction foci greater than 3 mm. Nineteen teeth (51.35%) examined after 1-2 years met the criteria of 8 points. Of these, 4 teeth (15.38%) were assigned to resorption group II. The group with questionable results included 10 teeth (27.02%), whose criteria corresponded to 4-6 points. All of them were examined 1–2 years after completion of treatment and belonged to resorption groups II and III, i.e., these were teeth with the most severe pathology. We classified one tooth (2.7%) as unsuccessful; signs of resorption of the filling material were observed in the RC two years after treatment. Although no destructive focus was observed, the periodontal ligament space in the apical region was expanded and there were no signs of cementum-like tissue formation.

Of the 18 teeth treated with Trioxident, 10 were re-examined. Of these, no endodontic treatment failures were noted; a questionable outcome was observed in one case (10%), and treatment was successful in nine cases (90%).

### 3.5 Evaluation of the results of endodontic treatment of teeth with periapical pathology.

We have developed a treatment method for patients with exacerbation of apical periodontitis and various conditions of the apical foramen of permanent teeth. It incorporates a combination therapy strategy aimed at stimulating the regeneration processes of the periapical complex. The use of the proposed ESs allows for expanded indications for conservative treatment of this pathology and achieves a lasting therapeutic effect (Table 6).

**Table 6** Long-term results of endodontic treatment depending on the selected endodontic sealant

| Filling material | Treatment results | | | | | |
|---|---|---|---|---|---|---|
| | Successful treatment | % | Questionable result | % | Unsuccessful treatment | % |
| Foredent | 39 | 47.56 % | 41 | 50.00 % | 4 | 4.88 % |
| Sealapex | 30 | 81.08 % | 6 | 16.21 % | 1 | 2.70 % |
| Trioxident | 9 | 90 % | 1 | 10 % | - | - |

All of these teeth were not divided into groups based on the degree of apical constriction destruction. Therefore, it was decided to examine the results of endodontic treatment not only based on the ES used, but also based on the degree of apical constriction destruction. In this case, completely different results were obtained, which, in our opinion, are more reliable.

To study the treatment data, long-term outcomes were assessed based on clinical and radiographic findings. For this assessment, follow-up observations of patient groups were conducted over a period of up to 4 years, and treatment outcomes were compared from the start of treatment to 2 years, and from 2 to 4 years. The percentage of complications was recorded depending on the presence or absence of clinical manifestations and radiographic evidence of persistent inflammation. If the inflammation grew, the prognosis of the treated tooth worsened (Table 7).

**Table 7** Evaluation of failures of endodontic treatment of teeth with chronic apical periodontitis in the acute stage depending on the state of apical constriction and the selected endodontic sealant

| Number of teeth / % of treatment failure | Groups | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Preserved constriction (I) | | Partially destroyed (II) | | | Destroyed constriction (III) | | |
| | Foredent | Sealapex +gutta-percha pins. | Foredent | Sealapex +gutta-percha | Trioxident | Foredent | Sealapex +gutta-percha pins | Trioxident |
| One year after treatment | | | | | | | | |
| Number of teeth | 55 | 64 | 20 | 21 | 7 | 7 | 9 | 11 |
| % of treatment failure | 14. 6 % | 3.13 % | 39 % | 4.8 % | 8 % | 52.86 % | 12 % | 9 % |
| 2 years after treatment | | | | | | | | |
| % of treatment failure | 21 % | 4.8 % | 44 % | 5.6 % | 8 % | 80 % | 15 % | 9 % |
| 4 years after treatment | | | | | | | | |
| % of treatment failure | 32 % | 9 % | 65 % | 7 % | 11 % | 92 % | 20 % | 9 |

In the group with preserved apical constriction, the failure rate over a 2-year period for Foredent exceeds that of Sealapex by 4.4 times. In the group with partially destroyed apical constriction, this ratio reaches 7.9 times for Sealapex and 5.5 times for Trioxident. With destroyed apical constriction, the failure rate of endodontic treatment after using Foredent reaches 80%, which is 5.3 times worse than that of Sealapex and 8.9 times worse than that of Trioxident. We hypothesize that, under the influence of masticatory load, fluid flow from the periodontium causes ES washout and disruption of the periodontal seal. Thus, the wider the apical constriction, the faster the ES washout and the appearance of signs of inflammation. The advantage of Trioxident is its resistance to fluid pressure due to its strength and minimal cracks between the material and the periodontal wall. Treatment results after 4 years confirm a trend toward a worsening prognosis.

### 3.6 Results of statistical research methods.

In the group of teeth with preserved apical constriction, the Kruskal-Wallis test was highly significant ($p = 0.000029$). Therefore, the characteristics of the experimental groups differ significantly from each other, and the alternative hypothesis is accepted: each group does not have an identical distribution of values in the population. This suggests that the use of Sealapex produces better results than Foredent. When comparing the treatment results of teeth in the second group using Trioxident and Sealapex filling materials with gutta-percha pins, a minimal discrepancy of 0.43 points between the sample means was revealed. The t-critical value is 2.1, which is higher than the t-statistic of 0.83. Therefore, the null hypothesis was confirmed, and no statistical differences in the use of filling materials were detected. In the Kruskal-Wallis analysis comparing the Sealapex and Trioxident groups, we obtained a p value of (0.642) > 0.05. Therefore, no statistical differences in the efficacy of these products were detected. When comparing the Sealapex and Trioxident groups, p = 0.678 > p = 0.5 and 0.05, indicating no statistical differences in these groups even with an increased threshold p value. In the group of teeth with severely destroyed apical constriction, in the Kruskal-Wallis analysis comparing the Sealapex and Trioxident groups, we obtained a p value of (0.3684) > 0.05. When evaluating all three groups, according to the Mann-Whitney analysis, we obtained a highly significant p value (0.0007), indicating the advantage of using Trioxident and Sealapex with gutta-percha pins compared to Foredent.

## 4. Discussion.

It should be noted that diagnosing periapical lesions using radiographic examinations plays a key role. With its help, the physician can correctly assess the initial clinical situation in order to determine the patient management tactics and select the most appropriate ES for high-quality obturation of the RC.

Depending on the state of the apical constriction, 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 its equivalent is recommended. For teeth with severely destroyed constriction, root canal filling with Trioxident is recommended using the typical method. This method allows for high-quality obturation in a moist environment, creating a kind of monoblock that firmly bonds with the root canal wall. Based on previous studies, 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 RC and the difficulty of its placement in this case. For filling apical constriction in this group of teeth, it is possible to use Trioxident analogues with similar physicochemical properties.

Currently, there is no single assessment tool for endodontic treatment outcomes that meets all requirements. Assessing the quality of treatment for teeth with periapical pathology is particularly challenging. For this purpose, we have proposed the "Periapical Index for Assessing the Quality of Endodontic Treatment for Destructive Periodontitis." This scoring system for assessing the quality of endodontic treatment allows for statistical analysis. The assessment criteria included in the "Questionable Success" section allow the practitioner to pay close attention to the tooth and attempt retreatment if there is no improvement in the "Successful Treatment" category within 4 years. A more detailed analysis of each proposed score allows us to focus not only on clinical but also radiographic features, which we believe are key. This detailed analysis allows for a qualitative comparison of the filling materials used for root canal obturation, taking into account the degree of apical constriction destruction. The latter factor can play a key role not only in the quality of the treatment performed but also in the long-term treatment outcomes. As a result, the clinician can carefully select the root canal sealer based on the underlying pathology.

The developed quality criteria will help practitioners reliably assess the results of endodontic interventions, taking into account the dynamics of observations, conduct analysis, and make timely decisions to address any deficiencies. The proposed periapical index for assessing the quality of endodontic treatment is easily accessible and does not require material costs, expensive equipment, or specially trained personnel. To carry it out, standard equipment of a dental clinic is required, which makes it possible to use this periapical index in an outpatient setting without additional time costs for its implementation.

The proposed index allows the clinician to more fully assess the quality of treatment for destructive forms of periodontitis, a pressing issue today. It makes it possible to assess the reliability of a tooth for subsequent prosthetic restoration or during orthodontic treatment.

The data obtained can be used for further research into improving the effectiveness of treatment for teeth with periapical pathology and destroyed apical constriction. This pathology poses certain challenges in the treatment of teeth with destructive forms of periodontitis due to the difficulty of inserting a filling material into the RC and ensuring its proper obturation. Further study of this problem will allow us to expand the range of methods used for RC obturation in this condition.

## 5. Conclusions.

The success of endodontic treatment is evidenced by quantitative data showing the presence or absence of exacerbation and changes in the size of the inflammatory lesion. Based on the assessment of the quality of endodontic treatment, it can be concluded that the best treatment results were achieved in the group with preserved apical constriction using Sealapex and gutta-percha pins (11.5% more effective than Foredent ($p < 0.005$)). In the group with partially destroyed constriction, both Sealapex and Trioxident demonstrated equal success rates. Over a period of up to 4 years, the success rates reached 93% and 89%, respectively. However, Foredent's effectiveness was only 35% ($p < 0.05$), which is associated with impaired canal obturation. In teeth with destroyed apical constriction, Trioxident demonstrated the best result (91% over a period of one year and over 4 years ($p < 0.05$)). Positive results in this group of teeth were achieved with Sealapex —from 88% to 80%, and Foredent—from 47.14% to 8%, respectively. Our research has shown that increasing the observation period for treated teeth in certain cases leads to a decrease in positive results.

Trioxident or its analogs are the material of choice for root canal fillings with destroyed apical constriction. The developed criteria for assessing the quality of root canal fillings for destructive forms of periodontitis will help the practitioner not only accurately evaluate the work performed and make timely decisions to correct deficiencies, but also predict the final outcome of the treatment.

**List of abbreviations:**

- CBCT: Cone Beam Computed Tomography
- RC: Root Canal
- ES: Endodontic Sealant
- PAI: Periapical Index
- ICD: International Classification of Diseases
- CDJ: Cementodentinal junction

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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 Results section of the manuscript.

**Ethics Committee Approval and Consent to Participate**

All participants signed informed 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.

The Bioethics Commission of the Federal State Budgetary Educational Institution of Higher Education "Donetsk State Medical University named after M. Gorky" dated 08.02.2024 No. 1/5-1 believes that the work performed by V.V. Glinkin meets the principles of the Helsinki Declaration adopted by the General Assembly of the World Medical Association (1997-2000), the Council of Europe Convention on Human Rights and Biomedicine (1997), the relevant provisions of WHO, the International Council of Medical Scientific Societies, the International Code of Medical Ethics (1983), the rules of the European Convention for the Protection of Vertebrate Animals Used for Experimental Research and Other

Scientific Purposes [European convention for the protection of vertebrate animals used for experimental and other scientific purposes. - Council of Europe, Strasbourg, 1986. - 53p.] and completely excludes limitation of the interests of the subjects and harm to their health and all ethical requirements.

**Consent for Publication:**

All clinical data and X-ray images were anonymized prior to analysis and publication, and the study does not contain any identifying information about patients. All X-ray images are clinical images and the intellectual property of the author, V.V. Glinkin.

**Standard Reporting Guidelines:**

The reporting of the observational components of this study was guided by the STROBE Statement, where applicable.

**Conflicts of Interest**

All authors declare no conflicts of interest.

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**Author contributions:**

Conceptualization, methodology, software, formal analysis, and visualization:V.V. Glinkin; Data curation, formal analysis, writing—original draft: V.V. Glinkina;
Supervision and writing—review & editing: V.V. Glinkin, V.V. Glinkina.
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