



Long-Term Clinical Outcomes of the Use of Endo-Sealants in the Treatment of Teeth with Destructive Forms of Apical Periodontitis

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Abstract

Radiographic examination remains the primary method used to assess endodontic treatment quality, and the search for objective evaluation methods remains relevant, as standardized criteria would let clinicians evaluate their own work objectively. **Objective:** To evaluate the effectiveness of treating teeth with periapical pathology based on the state of apical constriction, using clinical and radiographic examination to substantiate the choice of obturation material. **Methods:** The study involved 156 participants with 194 treated teeth (365 roots) with destructive forms of apical periodontitis in the acute stage, combining a retrospective cohort study with a randomized cohort study. Patients were grouped by the type of permanent root canal filling material used and the degree of apical constriction destruction, with long-term outcomes assessed over 6 months to 4 years. Radiographic examination employed an intraoral dental X-ray unit (5D2), a SOPIX 2 radiovisiograph (Acteon Group, France), and cone-beam computed tomography (CBCT) using a parallel technique. Root canals were filled with Foredent (82 teeth, 42.27%), Sealapex (94 teeth, 48.45%), or Trioxident (18 teeth, 9.27%), divided into three groups by degree of apical constriction destruction. The Periapical Index (PAI) and a newly developed “Periapical Index for Assessing the Quality of Endodontic Treatment of Destructive Periodontitis” were used for comparison. **Results:** In teeth with destroyed apical constriction, Foredent's failure rate reached 80%—5.3 times worse than Sealapex and 8.9 times worse than Trioxident. **Conclusions:** The best outcomes occurred in the preserved-constriction group treated with Sealapex and gutta-percha pins, 11.5% more effective than Foredent ($p < 0.005$). In the partially destroyed constriction group, Sealapex and Trioxident achieved comparable success (93% and 89% at 4 years), versus Foredent's 35% ($p < 0.05$), reflecting inadequate canal obturation. In destroyed apical constriction, Trioxident produced the best results (91% at one and four years, $p < 0.05$), while Sealapex declined from 88% to 80%, and Foredent from 47.14% to 8%.

Keywords:

apical periodontitis; radiographic examination; periapical index; endo-sealants; trioxident; foredent

1. Introduction

Despite recent scientific advances, diagnosing periapical pathology remains challenging [1,2]. Complications during endodontic treatment are relatively common, and treatment failure has traditionally been associated with persistent or recurrent endodontic infection. The inflammatory response in the periodontal region resembles that seen elsewhere in the body: once the irritant is removed—that

is, once the root canal is cleaned, shaped, and filled—healing proceeds similarly to healing in any other part of the body. Assessing the success of endodontic treatment dynamically, at regular intervals and using both clinical and radiographic data, is therefore advisable [3–5], since doing so allows the hard tissues of the tooth, the periapical tissues, and the surrounding bone to be evaluated together. Radiographic studies help identify and evaluate potential errors both during treatment and in its long-term out-

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comes [6,7]. Because two-dimensional imaging of three-dimensional structures significantly impairs the recognition of periapical pathology, cone beam computed tomography (CBCT) is preferable for these purposes, since it yields images with a lower risk of distortion [8]. CBCT's higher diagnostic value stems from its three-dimensional image [9–11], which allows more accurate determination of periapical lesion size [12], and combining CBCT with intraoral radiography is the most effective approach for this purpose. CBCT also enables detailed assessment of the heterogeneity of root canal (RC) obturation with an endodontic sealer (ES) [13], underscoring the importance of supplementing dental radiography with additional CBCT studies [14].

It is also important to recognize that while radiographic assessment of periodontal tissue condition is convenient for descriptive purposes, evidence-based medicine instead requires that the resulting data be formalized and that changes following treatment be tracked objectively over time. The generally accepted standard for evaluating treatment quality on radiographs is the criterion defined by Strindberg in 1956 [15], and the first scoring system for describing radiographic signs of periodontal pathology—the “Periapical Index”—was proposed by Ørstavik et al. in 1986 [16]; the index has since been modernized several times.

Current guidance recommends assessing endodontic treatment quality according to the European Society of Endontology's recommendations, which evaluate treatment outcomes and the subsequent course of the periapical process using three criteria—successful treatment, questionable treatment success, and treatment failure—based on clinical and radiographic examination over a 4-year period [17].

Comparing the results of different conservative periodontitis treatments requires comparative criteria capable of establishing statistically significant differences. Clinical and radiographic studies have traditionally served as the primary criteria for testing root canal obturation materials, typically conducted over several years to track recovery or disease progression; the resulting lack of standardization across studies, however, remains a major obstacle to objectively evaluating clinical outcomes in periodontal pathology treatment [18]—particularly when assessing the quality of endodontic treatment for teeth with compromised apical constriction.

In light of the above, the search for new methods of objectively assessing endodontic treatment outcomes remains highly relevant, and developing accessible standards for evaluating treatment quality would allow practitioners to objectively assess their own work and, in turn, improve their skills in a timely manner.

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

2. Materials and Methods

2.1. Clinical Study Participants

The study involved 156 patients with 194 treated teeth (365 roots)—107 women and 49 men, aged 20 to 60 years and older (mean 47 ± 5 years)—presenting with destructive forms of apical periodontitis in the acute stage, combining a retrospective cohort study with a randomized cohort study. Patients were assigned to groups based on the type of permanent root canal filling material used and the degree of apical constriction destruction, with long-term outcomes assessed over periods ranging from 6 months to 4 years. Patients were examined and treated at City Budgetary Institution of the DPR “City Dental Clinic No. 1 of Donetsk” (formerly “City Dental Clinic No. 1”) and the Department of Orthopedic Dentistry at Donetsk State Medical University of the Russian Ministry of Health, and were recruited between 2018 and 2021. Endodontic treatment was performed on participants diagnosed under ICD-10 codes K04.5–K04.8, K03.3 (“Pathological tooth resorption”), and K03.39 (“Pathological tooth resorption, unspecified”) (ICD-C), as well as the ICD-10 diagnosis of periodontitis affecting the pulp and periapical tissues, including acute exacerbation of chronic periodontitis of permanent teeth. All participants were free of underlying medical conditions, chronic erosive or ulcerative oral mucosal disease, and moderate-to-severe periodontitis that could compromise dental or general health. The retrospective component involved analysis of dental records (Form No. 043u) for patients with periapical lesions in permanent teeth treated with the study filling materials. Based on the study plan and prior laboratory and technical findings (scanning electron microscopy and spectral analysis of the test materials), the decision was made to evaluate and validate the clinical use of ES through clinical and radiographic analysis, according to clinical presentation and the condition of the apical tissues. Participants were divided into three groups based on the RC obturation material used—Foredent, Sealapex, and Trioxident, three widely used ESs belonging to different material classes—with Foredent used in 82 teeth (42.27%), Sealapex in 94 teeth (48.45%), and Trioxident in 18 teeth (9.27%). This distribution also reflected the state of the apical constriction of the treated teeth: Trioxident was not used in teeth with preserved apical constriction, owing to the difficulty

of inserting it into these root canals, but was used in 40.74% of cases involving destroyed apical constriction.

Patients were further divided into three groups according to the degree of apical constriction destruction; once this degree was determined, the treating physician selected the type of filling material to use for permanent root canal restoration.

2.2. Radiographic Examination of Periapical Pathology

All participants underwent radiographic examination using a 5D2 intraoral dental X-ray unit, a SOPIX 2 radiovisiograph (Acteon Group, France), and CBCT, following a standard technique applied before treatment, during treatment, after root canal obturation, and at later stages following treatment to track periodontal changes over time. Radiographic images were analyzed using established methods [19], and dental radiographs from the radiovisiograph were examined with a computer magnification program. Based on this radiographic examination, all participants were divided into three groups according to the condi-

tion of the apical constriction, corresponding to the radiographic criteria of Laux et al. (2000) [20].

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) [21] described by Ørstavik et al. [16] (Table 1), together with an assessment of the change in lesion area, calculated using the irregular circle formula ($S = \pi \times r1 \times r2$), where S is the area, π is 3.14, $r1$ is the radius of the smallest diameter, and $r2$ is the radius of the largest diameter. Healing dynamics of the inflammatory lesion were classified as satisfactory (a reduction in lesion size of more than 50% over six months to a year) or good (complete restoration of bone tissue, as assessed radiographically).

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 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.

2.4. Statistical Methods

Statistical processing of the results was performed in accordance with the study's objectives, using standard statistical methods. A personal computer and Microsoft Excel (Microsoft Corporation, Tulsa, USA) were used for data handling, and results were analyzed using the Statistica 6.0 software package (IBM® SPSS® Corporation, Chicago, USA). Statistical analysis relied on Student's t-test to compare mean values between unrelated, independent groups. The Kruskal-Wallis rank test—an analysis of variance based on ranks—was used to assess quantitative differences between the sealers studied, with post hoc comparisons performed using the Mann-Whitney U test to evaluate differences between two independent samples for any quantitative variable.

2.5. Traditional Treatment Methods

Traditional endodontic treatment methods are described according to the unified clinical protocol “Diseases of the Pulp and Periapical Tissues; Periodontitis; Acute Exacerbation of Chronic Periodontitis of Permanent Teeth,” adopted in the Russian Federation. Treatment for patients with periodontitis aims to address several objectives simultaneously:

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.

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 and tooth function is preserved.	Within 4 years after endodontic treatment, the bone structure is homogeneous, the periodontal ligament space is 0.5–1 mm wide, and the cementodentinal junction has formed in the apical area; the root canal is tightly obturated throughout its entire length.	9
		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, and signs of cementodentinal junction formation are present.	8
		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, the cementodentinal junction has formed in the apical area, and the root canal is tightly obturated.	7
Questionable result	Post-obturation pain persists for the first 5–7 days; discomfort with chewing, percussion, and palpation may persist for a month or more after treatment.	Partial restoration of the periapical lesion within 1 year, with full restoration of the lesion within 2 years; the periodontal ligament space is 1–2 mm wide, with no signs of cementodentinal junction formation, though the root canal is tightly obturated.	6
Unsuccessful treatment	Tooth mobility is normal, though one exacerbation is possible within 6 months after endodontic treatment.	The size of the periapical lesion does not decrease within 6 months after completion of endodontic treatment, but restoration of the lesion occurs within 2 years. The periodontal ligament space is uneven in the periapical area, with no signs of cementodentinal junction formation, though the root canal is tightly obturated.	5
		Restoration of the destruction focus within 2–4 years, with the destruction focus decreasing by no more than 1/3–1/2 of its original size and no signs of cementodentinal junction formation—indicative of improper endodontic treatment of the root canal and its obturation.	4
	Pain persists during treatment, and post-obturation pain persists for the first 14 days.	Reduction, but persistence, of bone destruction in the periapical lesion of any size for up to 4 years, with no cementodentinal junction (CDJ) formation—indicative of improper endodontic treatment and obturation of the root canal.	3
	Symptoms of inflammation include pain on percussion and palpation in the root apex area, with possible signs of a fistula, hyperemia of the alveolar mucosa, and abnormal tooth mobility for up to 1 year after endodontic treatment.	No changes in the periapical lesion for more than 4 years and no signs of cementodentinal junction formation, indicative of improper endodontic treatment and obturation of the root canal.	2
		The bone destruction lesion is enlarged, with no signs of cementodentinal junction formation—indicative of improper endodontic treatment and obturation of the root canal—and possible signs of resorption of the filling material within the canal.	1

When conservative treatment proves unsuccessful or impossible, conservative-surgical or surgical approaches are considered instead: apical resection, hemisection, coronal-radicular separation, or tooth extraction. Several 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 clinical presentation, symptoms, and diagnosis, and can range from dynamic observation to tooth extraction.

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

First visit:

1. Antiseptic treatment of the oral cavity (rinsing).
2. Pain relief (if necessary).
3. Cleaning the tooth surface of 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, and 0.15% decamethoxin solution); phenolic compounds (5% phenol solution, 1% camphor-*para*-monochlorophenol 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 clinician may choose a treatment strategy involving leaving a calcium-containing preparation in the RC during the first visit or a 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.

Second visit:

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).

Third visit:

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.

Fourth 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 restoration made of glass ionomer cement or light-cured or chemically cured composite resin.
5. Occlusion correction, grinding and polishing of the filling.
6. If the IROPZ is >0.4–0.8, referral for prosthodontic treatment. IROPZ - occlusal surface damage index. This indicator was proposed to objectively assess the degree of damage to dental hard tissues.

7. If surgery is necessary, the patient is referred to an oral surgeon.

The endodontic treatment plan described above does not detail recommendations for treating teeth with acute exacerbation of chronic apical periodontitis across vary-

ing degrees of apical constriction, nor does it resolve the question of leaving the tooth open without a temporary sealed restoration during the first visit. We therefore developed a dedicated method for endodontic treatment of teeth with this condition.

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	Perform according to 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 s; 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 obturated.
5.	Final condensation of the material	Excess filling material accumulating above the canal orifice should be pushed into the canal with force using a cotton pellet (for pastes), a probe or a plugger (for cements).

Table 4: Root canal filling algorithm using a single point 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 point	Select a pin equal in size to the last instrument used at the root apex; disinfect the pin for 5 min 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 points (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 s; 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.

Table 4: *Cont.*

Stages	Contents
7. Insertion of accessory points (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.

2.6. Proposed Treatment Method

This treatment regimen addresses teeth with acute exacerbations of chronic periodontitis across varying degrees of apical constriction destruction. Protocols for the study were established before treatment began, and all resulting data were 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 a previous restoration and coronal 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 findings, each patient was diagnosed, treated, and monitored for treatment quality.

Endodontic treatment followed a standardized protocol of instrumental and medicinal preparation, with the working field always isolated using a rubber dam.

A normal physiological apical foramen measures 0.1–0.2 mm, corresponding to an ISO size 10–20 file. In long-term inflammatory processes, however, the apical constriction can change, and the cementodentinal junction can become disrupted; patients were therefore divided into three groups—those with preserved constriction, partially destroyed constriction, and severely destroyed constriction—according to the radiographic criteria of M. Laux (2000):

1. Teeth without signs of resorption.
2. Teeth with signs of moderate resorption, which were visualized on radiographs as a blurred, uneven root contour.

3. Teeth with signs of severe resorption, visualized on radiographs as distinct radiolucent depressions or shortening of the root apex.

Radiographic examination of 194 teeth with destructive forms of apical periodontitis detected root apex resorption in only 47 cases (24.22%).

Visit 1:

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. Removal of necrotic tissue, irrigation of the carious cavity with 5.2% NaOCl, and access to the root canals.
5. Primary treatment of the coronal and middle thirds followed preliminary scouting of 2/3 of the root canal, undertaken to evacuate necrotic debris and prevent blockage of the apical third by dentin filings and infection of the periapical tissues.
6. After clearing and removing obstructions from the coronal portion, an “apical third reconnaissance” was performed, followed by determination of the working length: the stop was set to a mark corresponding to the average estimated length of the canal being treated, with deviations of up to 2 mm in either direction considered acceptable given individual tooth characteristics within this group. In cases of root apex resorption, root canal preparation for filling was completed 0.5 mm short of the radiographic apex (1.5 mm in total for extensive resorption, 2 mm or more short of the apex); when exudate was present, the apical foramen was widened to ISO 25.
7. Before instrumenting the RC, its approximate working length was determined. Histologically, working length refers to the distance from the point marked on the crown to the cementodentinal junction, close to the apical constriction. Back in the 1990s, the apical constriction was defined as the narrowest part of the root canal with the smallest diameter of blood

- supply, where preparation to this level provides the most favorable histological conditions for healing. To determine the endpoint of chemomechanical treatment, both primary (electronic apex locator) and additional (radiographic, periodontal sensitivity testing, tactile, and paper point) methods were used.
8. 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 followed, 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 (preserved constriction). If no resistance to instrument advancement occurred 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; when an obstruction to apical movement was felt and the apex locator signaled accordingly, an X-ray examination was again performed, the instrument removed, and the working length recorded—this condition was classified as GROUP II (partially disrupted constriction).
 9. If no resistance was encountered, no further file enlargement was performed. A 40.02 K-file was inserted until the apex locator signaled that the instrument had passed beyond the apical foramen, then withdrawn coronally by 0.5–1 mm until a 0.2–0.7 mm reading appeared on the apex locator display. A radiograph was then taken, and the file was removed to establish the working length; these teeth were classified as Group III (severely compromised apical constriction) (Figure 1).
- 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 1a). The CBCT section of tooth 47 additionally measures bone destruction in two planes (Figure 1b).
- Teeth with radiographically detectable root resorption present a particular treatment challenge, since this finding indicates extensive destruction at the root apex. In such cases, it may be necessary to first measure the apical foramen using a radiovisiograph scale or a CT scan; Figure 2 illustrates one possible error in determining the working length of the canal.

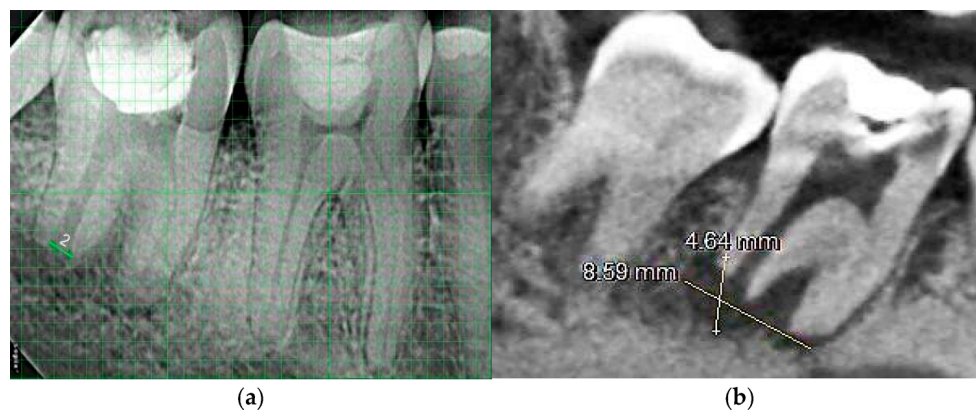


Figure 1: (a) Radiovisiographic image of tooth 47 (b) CBCT section of tooth 47.

This radiograph shows a tooth with acute exacerbation of chronic apical periodontitis: the periodontal ligament space is dilated, and a well-defined, rounded, radiolucent area is visible at the apex, surrounded by a zone of perifocal osteosclerosis, with erosion of the root apex.

Using tactile assessment and periodontal sensitivity testing, the working length was determined incorrectly: a 35.02 K-reamer was inserted into the root canal, extending the instrument tip 2 mm beyond the canal into the periapical tissues. To verify apical foramen size, a radiopaque

temporary filling material based on calcium hydroxide can be used in addition to conical gutta-percha points.

10. To obtain more accurate data when verifying apical foramen size without a radiovisiograph or CBCT (Figure 3a), we proposed a method for calculating apical foramen size using a gutta-percha point.
11. For this purpose, 25.06 gutta-percha points were used, with scissors employed to shorten the point in

1 mm increments until reaching the stop at the apex, 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.

Shortening the point by 7 mm using this formula yields 67, corresponding to an ISO file size of 65, or 0.65 mm: $25 + 6 \times 7 = 67$.

After determining the apical stop with a calibrated gutta-percha point, a radiographic examination was performed to more precisely establish the working length of the canal. The canal was then instrumented, chemically treated, and filled with a calcium-containing, non-

hardening sealer to the full working length (**Figure 3c**); machine files larger than 25.06 were not required.



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

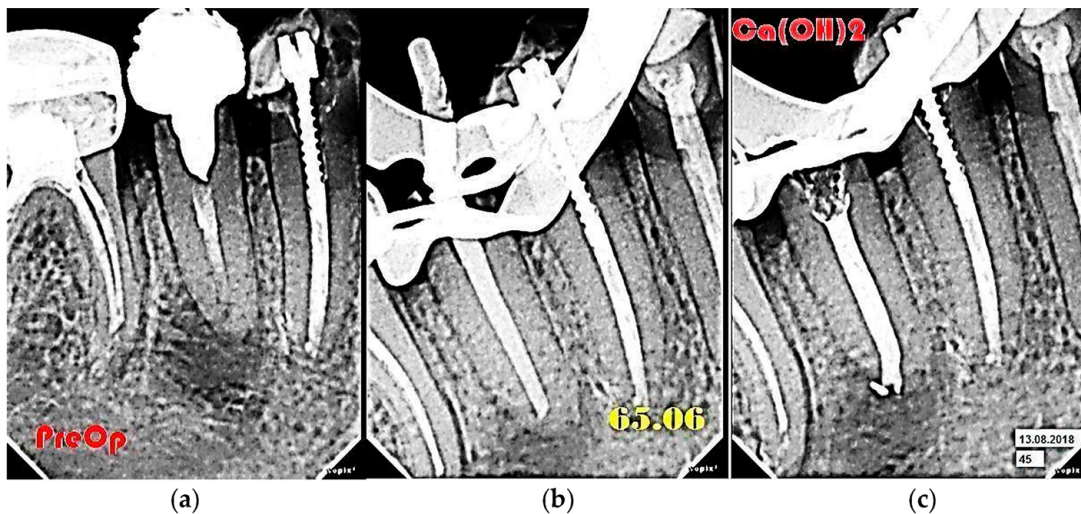


Figure 3: Radiographs of tooth 45: (a) initial situation; (b) image with a calibrated gutta-percha pin of 06 taper; (c) Image with a temporary calcium-containing material in the root canal.

12. For antiseptic treatment of the RC, as recommended in the clinical protocols, a 5.2% NaOCl solution from the Russian company TechnoDent was used, in accordance with TU 9391-001-67200978-2010; combined treatment employed an EDTA-based preparation ("EndoZhi No. 2," VladMiVa, per TU 9391-041-45814830-2001).
13. After antiseptic treatment, the CC were filled with Apexdent (VladMiVa, TU 9391-071-45814830-2001), which contains calcium hydroxide and creates a high pH environment (pH 12.5). Apexdent was chosen because calcium hydroxide-containing preparations have previously been shown to reduce bacterial counts in destructive periodontitis treatment.
14. The tooth cavity was hermetically sealed with Unitsem (VladMiVa; ISO 10993-11-2011, GOST R 52770-2007); nonsteroidal anti-inflammatory drugs, antibiotics, sulfonamides, antihistamines, and physical therapy were not prescribed.

1. Second visit, two weeks later, if there are no signs of inflammation: 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 of the studied endodontic 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 continued until a positive clinical result was achieved: no exacerbation of the inflammatory process, the tooth withstanding functional load, and periapical bone tissue indicating stabilization of the process.

3. Results

Long-term clinical outcomes of endodontic treatment were analyzed.

3.1. Complications of Treatment of Teeth with Periapical Pathology

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

Radiographic examination ([Figure 4c](#)) revealed vertical and horizontal root resorption with a porous structure in the buccal roots, whose tissues showed increased translucency. In the apical regions of the roots, uneven surfaces of varying width with unclear contours and increased translucency were observed, while shadows within the RC lumens appeared as heterogeneous, linear darkened areas with unclear contours—matching the density and configuration of ES fragments and suggesting resorption of the 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 comprised 66 participants treated for 82 (42.27%) teeth using Foredent as an ES; exacerbations of chronic periodontitis were more common among individuals over 60

years of age in this group. 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, radiographic results are presented for treatment of tooth 25 with root apex resorption ([Figure 5](#)). The patient presented 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 corresponding to the metal framework of the crown, with partial RC obturation manifesting as a non-uniform radiographic shadow in the middle third of the RC, a narrow band of darkening along the distal canal surface, and similar findings in the apical third. The periodontal ligament space is dilated, appearing as a clear band between the root surface and the compact layer of the socket, and a focus of alveolar bone destruction with fuzzy oval contours and marked cancellous tissue lucency is observed in the periapical region of tooth 25, extending medially and surrounded by an uneven zone of perifocal osteosclerosis; apical resorption appears as a radiolucent depression on the medial surface ([Figure 5a](#)). CBCT sections confirm bone destruction in the apical region as an area of increased transparency, uneven in width with fuzzy oval contours ([Figure 5b](#)).

Following treatment, the RC was filled with Foredent, and an anchor pin was placed in the canal with Unitsem three days later. At the six-month follow-up, the patient reported no complaints; objectively, the tooth was covered with an artificial crown serving as an abutment for a fixed bridge. The control radiograph shows a bright shadow in the RC corresponding in radiopacity to the metal pin, with tightly obturated RC walls. Apical root resorption remains present as a radiolucent depression on the medial surface, the periodontal ligament space remains widened, and bone tissue radiolucency in the periapical region has increased.

A year later, the patient returned complaining of a toothache in the upper left jaw that worsened when biting down on the tooth. A radiograph revealed a bright shadow in the RC corresponding in radiopacity to the metal post, though filling material was no longer visible around the post apex; the RC walls remained tightly obturated, but resorption of the filling material was observed in the apical third of the root, alongside continued apical root resorption. The periodontal ligament space was dilated, and a bone tissue lesion with ill-defined contours and slight lucency of the spongy bone was observed in the periapical region, extending medially and surrounded by a uniform band of perifocal osteosclerosis ([Figure 6](#)).

Following retreatment, the RC was filled using Tri-oxidant, and the patient has had no complaints in the five years since.

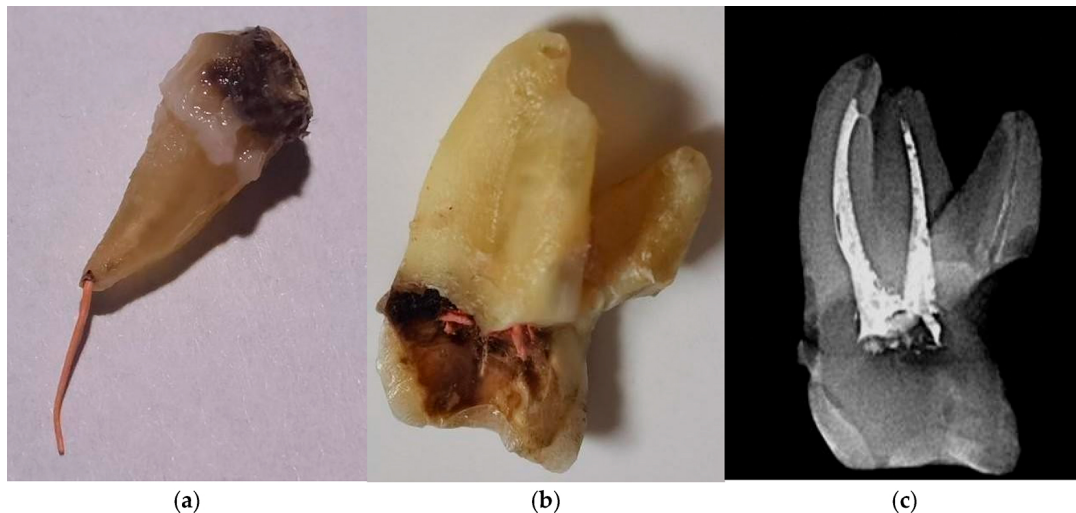


Figure 4: Photo of tooth 35, extracted 2 years after treatment. (a) Gutta-percha pin removed through the destroyed apical constriction. (b) Horizontal and vertical root resorption of tooth 17 2 years after filling. Thinning of the buccal root wall along the entire length, shortening of the roots along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

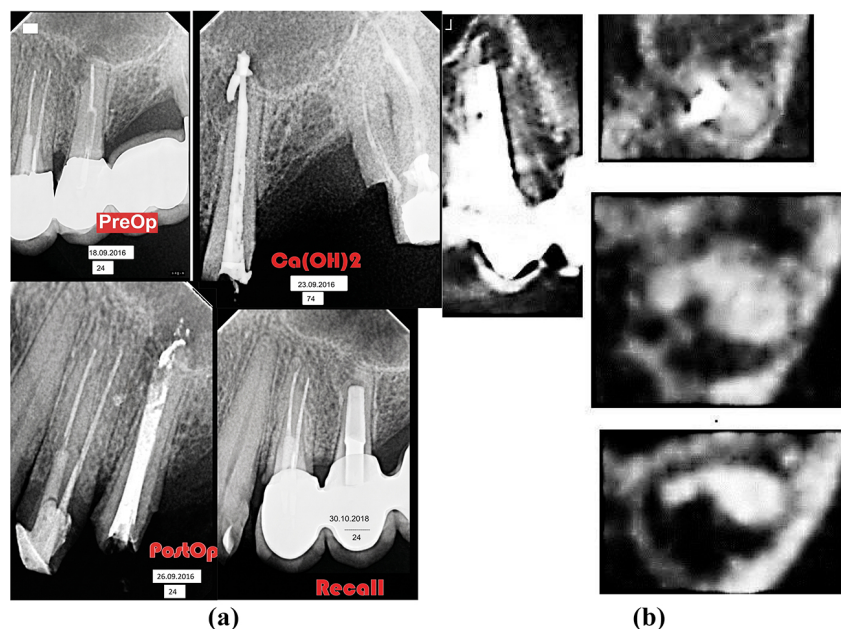


Figure 5: Radiographs of tooth 25: (a) diagnostic, at the time of treatment, and 25 months after completion of treatment; (b) diagnostic CBCT of tooth 25.

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 comprised 72 participants treated for 94 teeth using Sealapex ES with gutta-percha pins via the lateral condensation method; exacerbations of chronic periodon-

titis were more common among individuals over 50 years of age in this group. Among the treated teeth, 64 had preserved apical constriction (53.78%), 21 (43.75%) had partially destroyed constriction, and 9 (33.33%) had destroyed constriction. As a second clinical example, radiographic results are presented for treatment of tooth 37 with partially destroyed apical constriction (Figure 7).

After 14 months, radiographic imaging showed the root canals tightly obturated throughout their entire length,

with shadows in the RC appearing as linear, clear areas with well-defined contours matching the density and configuration of fiberglass posts. The periodontal ligament space remained within normal physiological limits, with no bone destruction, and this favorable trend continued thereafter.

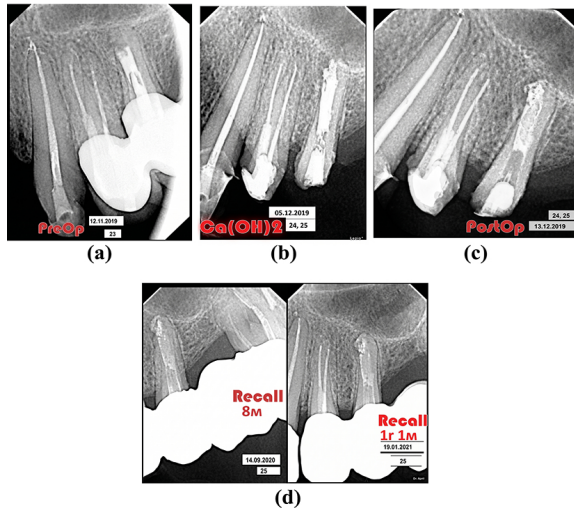


Figure 6: Radiographs of tooth 25. (a) 3 years and 2 months after completion of treatment (b) during retreatment (c) 8 months after completion of treatment (d) 13 months after completion of treatment.

3.4. Results of Treatment of Teeth with Periapical Pathology Using Trioxident

The third group comprised 18 participants treated for 18 teeth (36 roots) with Trioxident—five single-rooted, eight two-rooted, and five three-rooted teeth—drawn primarily from patients aged 20–30 years. In only two cases, roots in the third group (with destroyed apical constriction) were filled with Trioxident alone; the remaining two roots were instead 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 shows a shadow with jagged peripheral edges in the coronal portion, corresponding in radiopacity to the filling material, with the periodontal ligament space expanded along the distal root surfaces and the alveolar compact plate compromised. Resorption of the distal root apex appears as a uniform radiolucency with rough, truncated cone-shaped outlines, alongside shortening of the distal root; using a radiovisiograph scale, the apical foramen was measured at 2 mm. A focus of bone destruction at the root apex shows unclear contours, an oval shape, increased radiolucency, and a partially preserved bone pattern. CBCT of

tooth 47 confirms increased bone radiolucency in the root area, spanning half the interradicular septum and extending the full length of the medial root to the alveolar crest, with radiolucency in the medial root area extending to the lower jaw border and unclear contours, measuring 8.59×4.64 mm; root apex resorption again shows uniform radiolucency with rough, truncated cone-shaped contours (Figure 8).

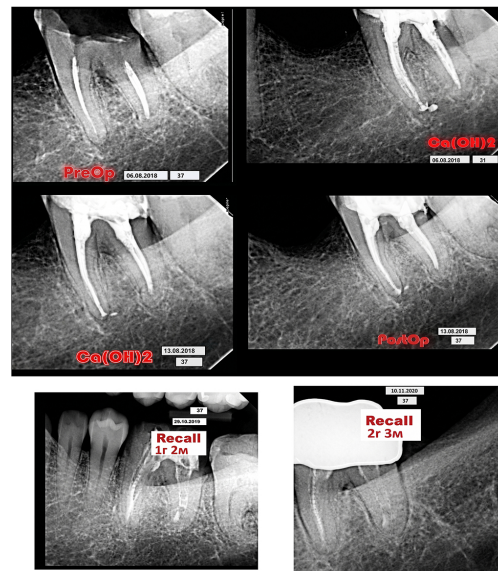


Figure 7: Radiographs of tooth 37: diagnostic; during treatment with a calcium-containing material for temporary root canal obturation; after permanent root canal filling; 14 months after completion of treatment; 2 years and 3 months after completion of treatment.

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

3.5. Periapical Quality Index for Endodontic Treatment of Destructive Periodontitis

Long-term clinical outcomes of endodontic treatment were assessed at 6 months, 1 year, 2 years, 3 years, and 4 years, with complaints collected and subjective sensations documented throughout the observation period. Each assessment included a visual examination—covering external, oral cavity, and affected-tooth findings—followed by radiographic diagnosis, with all data recorded in the patient's dental record. To track radiographic changes after

treatment in patients with destructive forms of chronic apical periodontitis, PAI values were assessed and changes in destructive lesion area (mm^2) were calculated. Since severe root resorption with destroyed apical constriction develops over an extended period, lesion size in this group could reach 1.5–2 cm, averaging 9.0 ± 2.3 mm; no correlation was found between lesion size and degree of resorp-

tion in teeth with preserved or partially destroyed constriction, where average lesion size was 6.5 ± 2.5 mm. Lesion size was therefore assigned a baseline weighting of 100%, with its change from initial size monitored over a period of up to one year, and the PAI value was estimated as the mean for each group (Table 5).

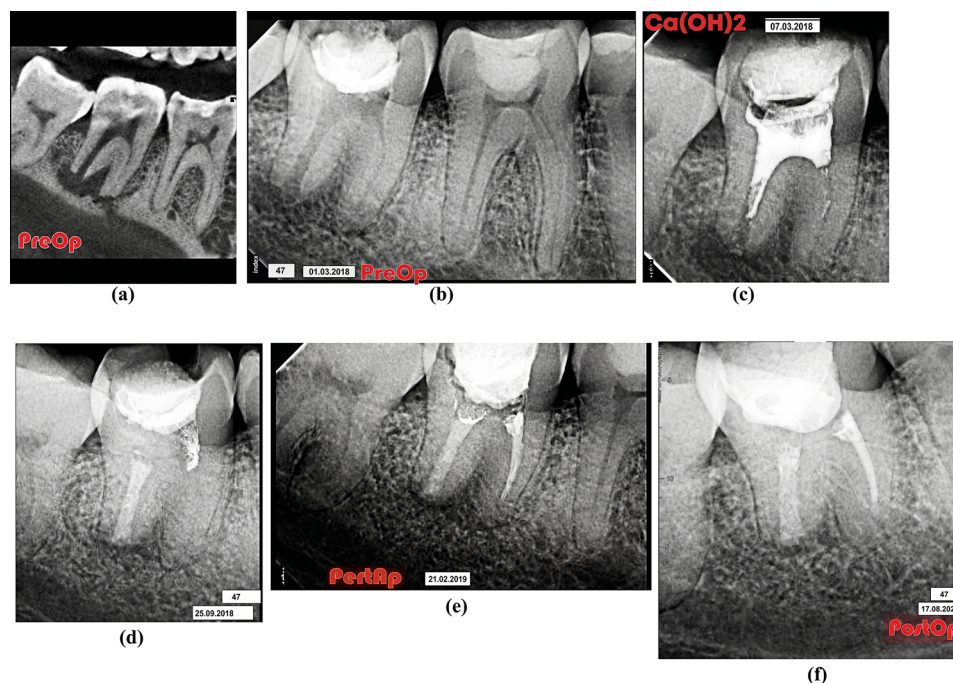


Figure 8: Diagnostic CBCT of tooth 47: (a) Radiographs of tooth 47; (b) diagnostic; (c) during treatment; (d) post-obturation CBCT after root canal filling with Trioxident; (e) 6 months after treatment (f) 1.5 years after treatment.

Table 5: Long-Term Clinical Outcomes 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	3.6 5± 0.1 3	3.85 ± 0.2	3.7 5± 0.1 3	3.69 ± 0.15	3.9 ± 0.2 4	4.14 ± 0.12	4± 0.2	3.9 ± 0.1 8
Area of the hearth (%)	100%							
Six months after treatment								

Table 5: *Cont.*

	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
Average PAI value	3.1 ± 0.1 6	2.85 ± 0.2	3.1 5± 0.1 5	2.6± 0.1	2.6 ± 0.2 4	3.6± 0.12	2.7± 0.2	2.6 ± 0.1 8
Area of the hearth (%)	63 %	50%	73%	65%	69%	80%	66%	53%
One year after treatment								
Average PAI value	2.9 ± 0.1 8	2.1± 0.16	2.9 ± 0.1 5	1.8± 0.1	1.9 ± 0.2	3.1± 0.2	2.1± 0.1	1.9 ± 0.1 8
Area of the hearth (%)	32%	10%	54%	12%	14%	63%	29%	18%

Currently, no uniform criteria exist for assessing the quality of endodontic treatment, and existing criteria are not fully suited to evaluating treatment quality 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, dividing outcomes into three categories—unsuccessful treatment, questionable outcome, and successful treatment—based on both clinical and radiographic signs. Radiographic assessment considered not only the quality of RC obturation but also dynamic changes in bone tissue, periodontium, and root.

Of the 82 teeth filled with Foredent, 56 teeth (68.29%) were re-examined a total of 89 times over periods ranging from 6 months to 4 years: 7 teeth at six months, 43 within one year, 27 after two years, 9 after three years, and 3 after four years. Although the periapical index changed for some teeth over this period, the overall picture reflected relatively successful endodontic treatment.

Of the 94 teeth filled with Sealapex and gutta-percha pins, 37 teeth (39.36%) were re-examined—7 at six months, 22 at one year, and 8 at two years. Seven teeth (18.91%) met the 7-point criteria and, on re-examination at six months, all showed a decrease in the bone destruction focus; this category included teeth from resorption groups I and II with destruction foci greater than 3 mm. Nineteen teeth (51.35%), examined after 1–2 years, met the 8-point criteria, of which 4 (15.38%) belonged to resorption group II. Ten teeth (27.02%) fell into the questionable-result category (4–6 points), all examined 1–2 years after treatment and belonging to resorption groups II and III—the teeth with the most severe pathology. One tooth (2.7%) was classified as unsuccessful, showing signs of filling material re-

sorption in the RC two years after treatment; although no destructive focus was observed, the periodontal ligament space in the apical region had widened, with no signs of cementum-like tissue formation.

Of the 18 teeth treated with Trioxident, 10 were re-examined. No treatment failures were noted among these teeth: one case (10%) showed a questionable outcome, and nine (90%) were successful.

3.6. Evaluation of the Results of Endodontic Treatment of Teeth with Periapical Pathology

We developed a treatment method for patients with acute exacerbation of apical periodontitis under varying conditions of the apical foramen in permanent teeth, incorporating a combination therapy strategy aimed at stimulating regeneration of the periapical tissues. The proposed ES expand the indications for conservative treatment of this pathology and achieve a lasting therapeutic effect.

These teeth were not divided into groups based on the degree of apical constriction destruction; we therefore examined endodontic treatment outcomes not only by the ES used but also by the degree of apical constriction destruction, yielding markedly different—and, in our view, more reliable—results.

To study the treatment data, long-term outcomes were assessed from clinical and radiographic findings, with follow-up observations of patient groups conducted over periods of up to 4 years and outcomes compared between treatment onset and 2 years, and between 2 and 4 years. The percentage of complications was recorded according to the presence or absence of clinical manifestations and radiographic evidence of persistent inflammation; where inflammation progressed, the prognosis for the treated tooth worsened accordingly (Table 6).

Table 6: 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 2-year failure rate with Foredent was 4.4 times that with Sealapex. In the group with partially destroyed apical constriction, this ratio reaches 7.9 times for Sealapex and 5.5 times for Trioxident, while in teeth with destroyed apical constriction, Foredent's failure rate reaches 80%—5.3 times higher than that of Sealapex and 8.9 times higher than that of Trioxident. We hypothesize that masticatory load drives fluid flow from the periodontium, causing ES washout and disruption of the periodontal seal—meaning the wider the apical constriction, the faster the ES washout and the earlier the appearance of inflammation. Trioxident's advantage lies in its resistance to fluid pressure, owing to its strength and the minimal gaps it forms between the material and the periodontal wall; treatment results after 4 years confirm a trend toward a worsening prognosis over time.

3.7. Results of Statistical Analysis

In the group of teeth with preserved apical constriction, the Kruskal-Wallis test proved highly significant ($p = 0.000029$), indicating that the experimental groups differ significantly from one another and supporting the alternative hypothesis that each group's values are not identically distributed—consistent with Sealapex outperforming Foredent. When comparing treatment results for teeth in the second group using Trioxident versus Sealapex with gutta-percha pins, only a minimal discrepancy of 0.43 points emerged between sample means; since the t-critical value (2.1) exceeded the t-statistic (0.83), the null hypothesis was confirmed, and no statistically significant differences were detected between these filling materials. The Kruskal-Wallis analysis comparing Sealapex and Trioxident similarly yielded $p = 0.642$ (> 0.05), again indicating no statistical difference in efficacy, and comparing the same two groups gave $p = 0.678$ (> 0.5 and > 0.05), con-

firmed no statistical difference even at an increased significance threshold. In the group with severely destroyed apical constriction, the Kruskal-Wallis analysis comparing Sealapex and Trioxident yielded $p = 0.3684$ (> 0.05). Across all three groups, Mann-Whitney analysis yielded a highly significant p value (0.0007), confirming the advantage of Trioxident and Sealapex with gutta-percha pins over Foredent.

4. Discussion

Diagnosing periapical lesions through radiographic examination plays a key role in treatment planning, allowing the clinician to correctly assess the initial clinical situation, determine the patient management strategy, and select the most appropriate ES for high-quality RC obturation.

Depending on the state of apical constriction, we recommend dividing teeth with destructive apical periodontitis into three groups. For teeth with preserved or partially destroyed apical constriction, Sealapex with gutta-percha pins (or an equivalent) is recommended; for teeth with severely destroyed constriction, root canal filling with Trioxident, applied using the standard technique, is recommended instead, since it allows high-quality obturation in a moist environment and forms a monoblock that bonds firmly with the root canal wall. Based on our earlier findings, we do not recommend using Trioxident to fill teeth with preserved apical constriction, given the high risk of seal failure in the absence of moisture in the RC and the difficulty of placement in this scenario; Trioxident analogues with similar physicochemical properties may instead be used for filling apical constriction in this group of teeth.

No single assessment tool currently meets all requirements for evaluating endodontic treatment outcomes, and assessing treatment quality for teeth with periapical

pathology is particularly challenging. We therefore propose the “Periapical Index for Assessing the Quality of Endodontic Treatment for Destructive Periodontitis,” a scoring system that supports statistical analysis. The assessment criteria within the “Questionable Success” category allow practitioners to monitor a tooth closely and attempt retreatment if it fails to progress to “Successful Treatment” within 4 years, while the detailed scoring for each criterion lets us focus on both clinical and radiographic features—the latter of which we consider key. This level of detail also enables a qualitative comparison of filling materials used for root canal obturation, accounting for the degree of apical constriction destruction, a factor that can shape not only treatment quality but also long-term outcomes; as a result, clinicians can select the root canal sealer more carefully based on the underlying pathology.

These quality criteria will help practitioners reliably assess the outcomes of endodontic interventions, track observations over time, conduct analysis, and make timely decisions to address any deficiencies. The proposed periapical index is easily accessible and requires no additional material costs, expensive equipment, or specially trained personnel—only standard dental clinic equipment—making it practical for outpatient use without added time demands.

This index also allows clinicians to more fully assess treatment quality for destructive forms of periodontitis, a pressing clinical issue, and to evaluate a tooth's reliability for subsequent prosthetic restoration or orthodontic treatment.

These findings can inform further research aimed at improving treatment effectiveness for teeth with periapical pathology and destroyed apical constriction—a condition that poses particular challenges due to the difficulty of inserting filling material into the RC and ensuring proper obturation. Further study of this problem should help expand the range of methods available for RC obturation in this condition.

5. Conclusions

The success of endodontic treatment is evidenced by quantitative data on the presence or absence of exacerbation and changes in inflammatory lesion size. Based on our assessment of treatment quality, the best outcomes occurred in the group with preserved apical constriction treated with Sealapex and gutta-percha pins, 11.5% more effective than Foredent ($p < 0.005$). In the group with partially destroyed constriction, Sealapex and Trioxident achieved comparable success rates, reaching 93% and 89%, respectively, over 4 years, while Foredent's effectiveness reached only 35% ($p < 0.05$), associated with inadequate

canal obturation. In teeth with destroyed apical constriction, Trioxident produced the best results (91% at both one year and four years, $p < 0.05$), while Sealapex declined from 88% to 80% and Foredent from 47.14% to 8% over the same period. Our findings further show that, in certain cases, extending the observation period for treated teeth leads to a decline in positive outcomes.

Trioxident or its analogues remain the material of choice for root canal filling in teeth with destroyed apical constriction. The quality criteria developed here for assessing root canal fillings in destructive forms of periodontitis will help practitioners not only evaluate their work accurately and make timely corrective decisions, but also predict final treatment outcomes.

List of Abbreviations

CBCT	Cone Beam Computed Tomography
CDJ	Cementodentinal junction
EDTA	Ethylenediaminetetraacetic Acid
ES	Endodontic Sealant
GOST	State Standard
ICD	International Classification of Diseases
IPROZ	Index of Restoration of the Occlusal Surface of the Teeth
IROPZ	Occlusal Surface Damage Index
ISO	International Organization for Standardization
PAI	Periapical Index
RC	Root Canal
STROBE	STrengthening the Reporting of OBServational studies in Epidemiology
TU	Technical Conditions
WHO	World Health Organization

Author Contributions

Conceptualization, Investigation, Software, Writing—Review and Editing, V.V. Glinkin; Investigation, Data Curation, Writing—Original Draft Preparation, V.V. Glinkina. All authors have read and agreed to the published version of the manuscript.

Availability of Data and Materials

The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Ethics Committee Approval and Consent to Participate

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) confirmed that the work per-

formed by V.V. Glinkin complies with the principles of the Helsinki Declaration adopted by the General Assembly of the World Medical Association (1964), the Council of Europe Convention on Human Rights and Biomedicine (1997), the relevant provisions of the WHO and the International Council of Medical Scientific Societies and completely excludes any limitation of the interests of subjects or harm to their health, meeting all applicable ethical requirements. (No. 83/5-1 dated 19.12.2019)

Human Rights Statement

All participants signed informed consent, and the study complies with the ethical principles governing clinical trials and the provisions of the World Medical Association's Declaration of Helsinki, fully excluding any infringement of patient interests or harm to their health.

Consent for Publication

Written informed consent for publication of clinical images (including radiographic images, cone-beam computed tomography sections, and photographs of extracted teeth) was obtained from all patients whose de-identified images appear in this manuscript, including those featured in the individual case examples (teeth 17, 25, 35, 37, 45, and 47). All radiographic, CBCT, and photographic images were reviewed and anonymized prior to analysis and publication; no image contains facial features, names, dates of birth, medical record numbers, or any other information that could identify an individual patient. Copyright to the original images belongs to the corresponding author, V.V. Glinkin, as the treating clinician who produced them.

Conflicts of Interest

The authors declare no conflicts of interest.

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AI Declaration

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

responsibility for the accuracy, originality, integrity, and scientific content of the manuscript.

Standard Reporting Guidelines

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

Supplementary Materials

Supplementary material associated with this article has been published online and is available at: <https://doi.org/10.69709/BIOMATC.2026.105057>.

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