Journal of Current Research in Oral Surgery
2026, Volume 6, Issue 1, Page No: 152-161

Available online at: www.tsdp.net

ISSN: 3062-3480

Original Article

Clinical and 3D Radiographic Outcomes of Biodentine Apexification in Necrotic Immature Permanent Incisors: A CBCT-Based Study

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Received: 05 February 2026; **Revised:** 25 March 2026; **Accepted:** 26 April 2026

ABSTRACT

The objective of this investigation was to evaluate the 12-month effectiveness of biodentine apexification for treating traumatized immature teeth presenting with necrotic pulps. A total of 85 human maxillary incisors with traumatized immature necrotic pulps, sourced from patients aged 10–50 years, were included in this study. Root canal therapy was initiated, and the Biodentine apexification protocol was performed in a single visit for each tooth. Intraoral periapical radiographs captured before and after treatment were utilized to evaluate periapical (PA) changes, shifts in root length (RL), and radiographic root area (RRA). Pre- and postoperative cone-beam computed tomography (CBCT) images were used to measure three-dimensional (3D) volumetric changes. Follow-up was conducted at 12 months posttreatment to examine clinical symptoms and responses to percussion and palpation. Descriptive statistics were generated for preoperative demographic information, patient-related data, and treatment success. A paired t-test was applied to assess the differences between preoperative and 12-month postoperative changes in RRA, RL, and 3D volumetric measurements of the studied parameters. Of the 49 teeth remaining at study completion, 48 were asymptomatic and functional. Upon comparing preoperative radiographs with those from the 12-month review using periapical index scores based on lesion dimensions, 79.16% of lesions were fully healed, while 20.83% were in the process of healing. Statistically significant ($P < 0.05$) gains were noted in RL (14.17%), RRA (40.87%), and dentin volume (26.63%). Findings from the 3D volumetric analysis indicate that biodentine apexification can facilitate 3D hard-tissue deposition, making it a viable alternative to traditional apexification materials.

Keywords: Apexification, Biodentine, Cone-beam computed tomography, Dentine volume, Immature teeth

How to Cite This Article: Santos V, Costa R, Teixeira B. Clinical and 3D Radiographic Outcomes of Biodentine Apexification in Necrotic Immature Permanent Incisors: A CBCT-Based Study. J Curr Res Oral Surg. 2026;6(1):152-61. https://doi.org/10.51847/kwhQQE2Dvx

Introduction

The recorded prevalence of traumatic dental injuries (TDI) stands at 15.2% [1, 2]. Despite this, TDI is an overlooked condition that could be placed fifth if added to the catalog of the globe's most common acute and chronic diseases and injuries. Investigators have appealed to International public health bodies to recognize TDI and incorporate it into the Global Burden of Disease study [3]. Incisor trauma occurring at an early age may cause root development to cease. This leaves practitioners facing a root with a wide-open apex (an immature tooth) and thin dentine walls, which call for root canal intervention [4]. Accordingly, an apexification material that facilitates ongoing root maturation after treatment completion is necessary.

Emerging calcium silicate-based bioactive cements have shown encouraging healing potential for immature, necrotic maxillary incisor teeth [4, 5]. A handful of clinical investigations employing mineral trioxide aggregate (MTA) have likewise demonstrated strong potential as an apexification cement [6, 7]. The utilization of Biodentine for apexification of the root end has not been widely explored. Furthermore, a review of the available literature revealed no prior cone-beam computed tomography (CBCT) studies with a substantial sample.

Hence, the goals of this clinical research were (1) to establish the clinician- and patient-oriented outcomes following treatment of traumatized maxillary incisors with biodentine apexification at the 1-year mark, and (2) to quantify two-dimensional (2D) variations in radiographic root area (RRA) and root length (RL), along with performing a three-dimensional (3D) volumetric analysis of these same parameters after 1 year of biodentine apexification.

Materials and Methods

Upon securing approval from the institutional ethics committee (CSICDSR/IEC/0125/2019), the study was registered in the Clinical Trials Registry of India (CTRI/2020/01/030658). A group of 78 patients, contributing a total of 85 maxillary incisors, was enrolled in the trial spanning June 2017 to March 2020. Written informed consent was obtained from each patient (or their guardian/parents, as necessary) before commencing treatment. Individuals aged 10 to 50 years were included. All designated maxillary incisors were either necrotic or unresponsive to cold pulp sensibility testing and featured open roots resulting from either incomplete root development—typical of younger cohorts—or apical resorption—characteristic of older cohorts. Teeth were deemed immature whenever a minimum apical foramen width of 1 mm was present [8]. The full set of inclusion and exclusion criteria for tooth selection is displayed in **Table 1**.

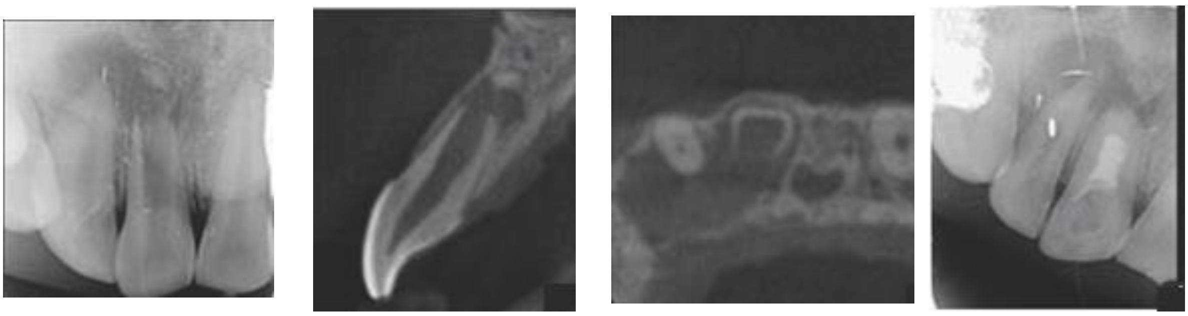
Table 1. Inclusion and exclusion criteria for the study

Inclusion criteria	Exclusion criteria
Maxillary incisors exhibiting pulp necrosis with a prior history of trauma and radiographic confirmation of wide open apices (Cvek's root development stage < 5) relative to the adjacent healthy tooth	Teeth unsuitable for post-endodontic restoration
Radiographic presence or absence of periapical (PA) lesions	Patients are unwilling to undergo CBCT imaging
Teeth either previously treated with root canal therapy or untreated	Teeth showing signs of vertical root fracture
Teeth with a healthy periodontal condition	Patients are unwilling to attend follow-up visits or present with compromised periodontal health
Patients with systemic conditions that may interfere with root canal therapy	

CBCT: Cone-beam computed tomography

Evaluation of preoperative radiograph and cone-beam computed tomography

The CBCT image acquisition process was explained to each patient before treatment. Scanning was performed with a Kodak CS 8100 3D system (Carestream Dental, Atlanta, USA), restricting the field of view to no more than 8 teeth, with settings of 80 kVp, 5 mA, 19.96 s, and a voxel dimension of 90 µm **(Figures 1a-1d)**. Interpretation of the CBCT datasets employed a previously defined periapical index (PAI) scoring method [9]. Using the periapical radiographs, baseline periapical status was determined by applying Orstavik's PAI system. Supplementary preoperative records included age, sex, symptomatology, and the initial categorization of root maturation [10].



a) b) c) d)

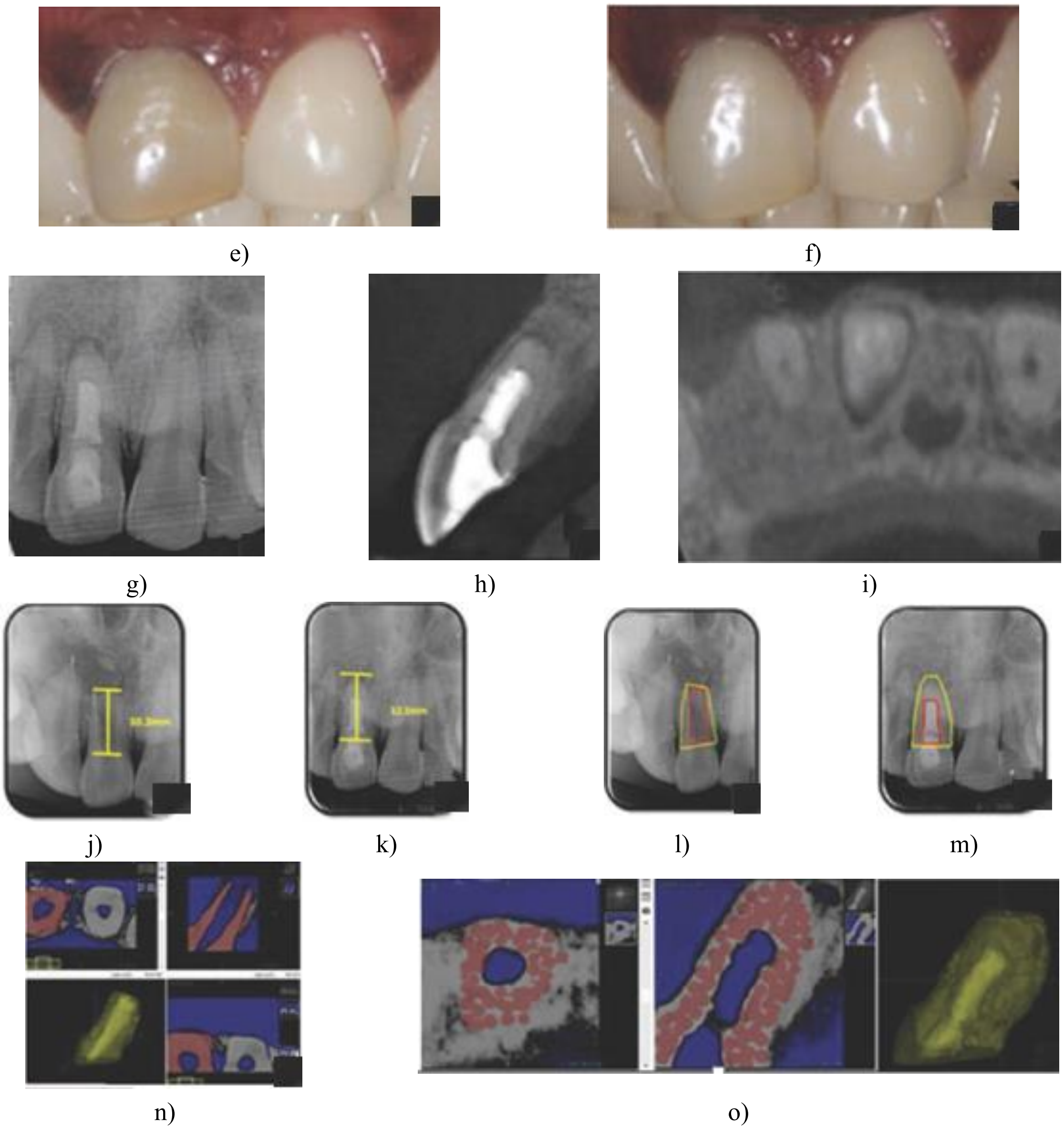


Figure 1. (a-d) Baseline radiograph and CBCT sections of a maxillary central incisor displaying a sizable periapical radiolucency, (e and f) Chromatic alteration caused by triple antibiotic paste was subsequently corrected through internal bleaching, (g-i) Follow-up radiograph and CBCT sections at 12 months of the maxillary central incisor, revealing augmented root length and remarkable periapical resolution, (j-m) Radiographic analysis via ImageJ software, (j and k) Pre- and posttreatment root length quantification, (l and m) Pre- and posttreatment root area quantification, (n and o) Dentin volume quantification using ITK SNAP software, (n) Baseline dentin volume quantification, and (o) Posttreatment dentin volume quantification.

Biodentine® apexification procedure

Canal instrumentation and the apexification protocol were executed entirely under dental dam isolation. An access opening was created in every tooth employing a high-speed diamond bur with water coolant. Following restrained shaping of the canal with manual K-files (Mani Co., Tochigi, Japan), the canal was flushed using a combination of saline (NS 500 mL, Sodium chloride 0.9%, Fresenius Kabi, Pune, India Pvt. Ltd) and povidone-iodine solution (Puradine, Leeford Healthcare Ltd, Mumbai, India). Flushing was delivered with a 24-gauge side-vented needle fitted to a standard syringe (Dispovan syringes, Hindustan Syringes and Medical Devices, Ltd., Faridabad, India). The working length was determined using a phosphor plate scanner (VistaScan Mini Plus; Durr Dental, Bietigheim-Bissingen, Germany). Once irrigation was complete, a freshly prepared triple antibiotic paste (TAP) (metronidazole, minocycline, and ciprofloxacin at a 1:1:1 ratio) blended with a glycerine carrier was inserted into the canal as an inter-appointment dressing using a hand K-file. When an incisor had received prior root canal therapy, the pre-existing obturation material was eliminated with K-files and H-files (Mani Co., Tochigi, Japan) before introducing the medicament. The access cavity was sealed with a provisional zinc oxide-eugenol cement (Dental Products of India, Ltd., Mumbai, India). Subjects were directed to return after a 15-day interval for definitive canal filling. Obturation was carried out by placing a Biodentine® (Septodont Healthcare Pvt Ltd, Raigod, India) apical barrier, with the middle and coronal canal segments backfilled using thermoplasticized Gutta-Percha (Super endo alpha and beta, B and L Biotech, Seoul, Korea).

The root fill was terminated 2–3 mm short of the cement-enamel junction to create room for internal bleaching agents in teeth exhibiting discoloration. The whitening phase commenced at the 2-month recall appointments **(Figures 1e and 1f)**. A blend of Sodium perborate tetrahydrate 96% (Lobachemie Pvt. Ltd., India) and hydrogen peroxide 30% (Nice Chemicals (P) Ltd, Kerala, India) constituted the bleaching formula. Fresh bleaching material was placed every 7 days, with three cycles completed per tooth. The access cavity and any fractured coronal portion were reconstructed with composite (Charisma Smart, Kulzer GmbH, Hanau, Germany).

Recall visits

Patients returned for clinical review at 12 months after treatment, with clinical appraisal including symptom inquiry, percussion and palpation testing, and follow-up radiographs and CBCT imaging. Recall timing targeted the precise 12-month mark, though visits within a ±2-month window of the planned date were included in the analysis. Posttreatment radiographs and CBCT scans were examined for periapical alterations following the same methodology applied preoperatively **(Figures 1g-1i)**. Teeth were also inspected for any posttreatment shade shift.

Radiographic assessment (radiographic root area and root length assessment)

Before undertaking the measurements, the assessor (SP) completed a standardization exercise employing instructional video material. The variation in RRA was quantified according to the previously outlined technique **(Figures 1j-1m)** [11]. To summarize, the initial and recall radiographs were first adjusted to correspond in size and resolution. Images belonging to each case were subsequently aligned and normalized against one another through the TurboReg plugin tool (Philippe Thevenaz, Biomedical Imaging Group, Swiss Federal Institute of Technology Lausanne, Lausanne, Switzerland) operating within the open-source platform ImageJ (version 1.47; National Institutes of Health, Bethesda, MD) **(Figures 1j-1m)**.

Calculation of RRA was performed as the percentage divergence between the overall root silhouette and the canal void (marked by gutta-percha and any radiolucent canal areas visible in recall radiographs) for each image, as detailed below:

- RRA = entire root contour - canal void
- Alteration in RRA (Δ RRA) = posttreatment RRA – baseline RRA
- Percentage alteration in RRA = (Δ RRA/baseline RRA) × 100
- RL was registered as a linear dimension from the CEJ straight to the apical terminus
- Alteration in RL (Δ RL) = posttreatment RL – baseline RL
- Percentage alteration in RL = (Δ RL/baseline RL) × 100.

Volumetric analysis with cone-beam computed tomography data

The CBCT datasets were exported in DICOM format with a voxel dimension of 90 µm. The entire CBCT acquisition was imported into the ITK-SNAP platform **(Figures 1n and 1o)** [12]. Responsibility for submitting all scans for segmentation fell to one author (SP), who used a dedicated instrument whose accuracy for root canal space demarcation had been established in earlier work [13]. Quantification of the volumes corresponding to the root's hard tissue component and the canal void (identifiable by the Gutta-Percha presence and radiolucent canal zones on recall radiographs) proceeded from the CEJ downward to the apical terminus for image sets obtained both before and after the intervention **(Figure 1o)**.

Definition of outcomes

Primary outcome

The central parameters under evaluation were the proportions of success, survival, and failure recorded for biodentine apexification in permanent immature maxillary incisors [7]. The criteria for success stipulated an absence of clinical manifestations and symptoms—specifically, pain, swelling, sinus tract emergence, and periapical radiolucency—as visualized on a two-dimensional (2D) periapical radiograph. The criteria for survival stipulated that the tooth remain in its position within the arch, free of clinical signs or symptoms, regardless of radiographic evidence of pathology. The criteria for failure stipulated that any singular or combined presentation from the following list was present: a radiolucency that neither diminished nor grew in size, the development of clinical manifestations or symptoms, the necessity of undertaking further root canal procedures beyond the original apexification, or the clinical decision to remove the tooth.

Secondary outcome

The ancillary endpoints selected were (1) the percentage variation in RRA and RL derived from 2D periapical image analysis, and (2) the variation in root volume derived from 3D CBCT image analysis **(Figure 2)**.

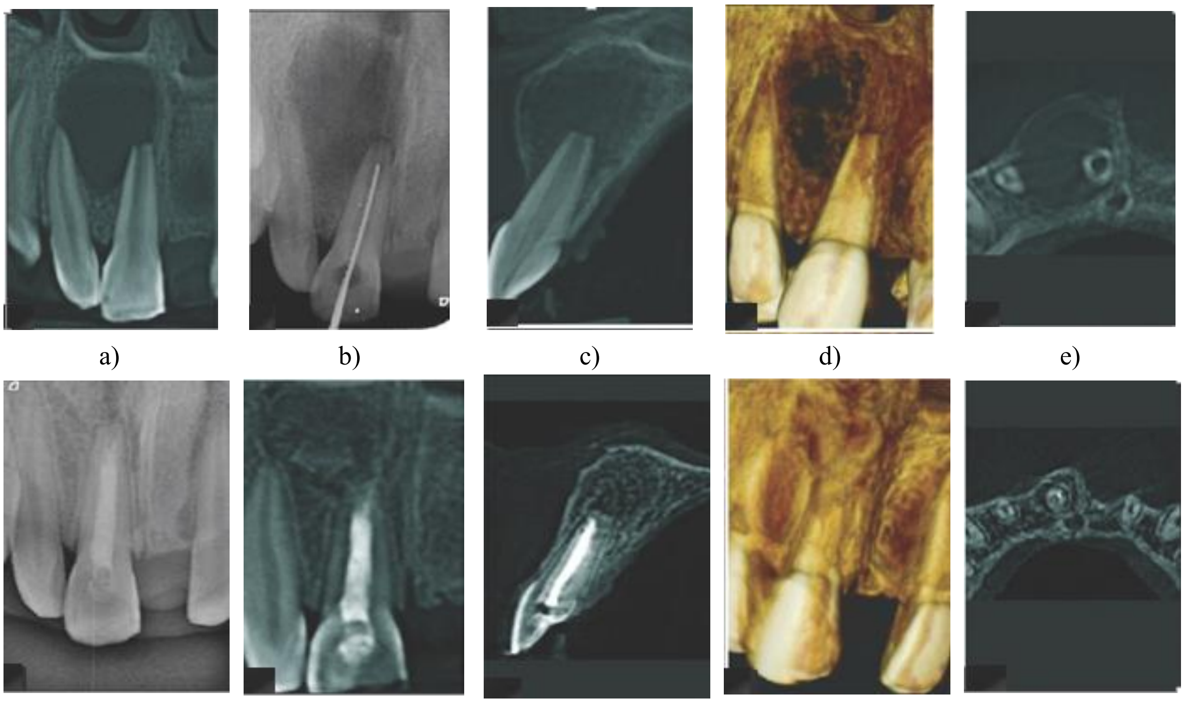


Figure 2. (a-e) Pretreatment periapical radiograph alongside cone-beam computed tomography (CBCT) captures of a maxillary central incisor displaying an open apex, together with a substantial periapical radiolucency, (f-j) Corresponding 12-month periapical radiograph and CBCT images demonstrating gains in root length and an outstanding periapical restoration.

Following an established classificatory scheme, outcomes were further sorted into those focused on the patient (tooth survival) and those oriented toward the clinician (radiographic and clinical evidence of healing/success, RRA, RL alteration, 3D alteration).

Statistical analysis

Derivation of descriptive statistics covered the preoperative demographic profile, patient-centered information, and overall treatment success. Application of the paired t-test permitted a direct contrast between the preoperative figures and those obtained at 12 months for RRA, RL, and 3D volume. The software package SPSS 23.0 (IBM Corp., Armonk, NY, US) performed all statistical analyses, and the significance threshold was set at $P < 0.05$.

Of the original cohort of 78 patients (enrolling 85 teeth), 42 patients (49 teeth) presented for the 12-month postoperative review, whereas contact was lost with 36 patients (36 teeth). The definitive analysis was therefore grounded in the data from 49 teeth. The age distribution of participants ranged from 14 to 48 years; males accounted for 56% of the sample and females for 44%. On average, the observation period lasted 14.26 months. The demographic characteristics and clinical profile of those studied are presented in **Table 2**.

Results and Discussion

Table 2. Demographic and clinical data of the study population

	Frequency
Gender	
Male	28
Female	21
Type of tooth	

Maxillary central	47
Maxillary lateral Cveks stage	2
Stage 2	3
Stage 3	19
Stage 4	27

Clinician-centered outcomes

Success, survival, and failure

At the 12-month recall, 98% (48/49) of the treated teeth remained in situ and showed no symptoms. Percussion tenderness could not be elicited from any tooth within this group of 48. The single tooth that met the failure definition at follow-up was subsequently extracted. Statistically significant ($P < 0.05$) quantitative alterations in root architecture—spanning RRA, RL, and 3D volume—were confirmed by the paired t-test after 12 months had elapsed from treatment **(Table 3)**.

Table 3. Test of significance for quantitative changes of root morphology at the 12-month follow-up

Quantitative changes in root morphology	Mean ± SD	95% CI (Lower bound)	95% CI (Upper bound)	P-value
Percentage change in root length (RL)	14.1698 ± 7.41364	−2.21025	−1.21479	0.000
Percentage change in radiographic root area (RRA)	40.8711 ± 17.45083	−16.89963	−12.04587	0.000
Percentage change in root dentin volume	26.2653 ± 20.4084	−81.40600	−60.66697	0.000
Duration of follow-up (months)	14.2653 ± 6.74776	—	—	—

Abbreviations: SD = Standard deviation, CI = Confidence interval, RRA = Radiographic root area, RL = Root length.

Periapical index and cone-beam computed tomography index score

Employing PAI grading criteria anchored to the extent of the lesion, the comparison of PAI values generated from preoperative radiographs, 12-month recall radiographs, and CBCT datasets **(Figure 3)** yielded the following distribution: 79.16% (38/48) of lesions had achieved complete resolution, while 20.83% were actively progressing toward resolution. At no point was a static or an enlarging radiolucency encountered.

PAI score	Valid percentage			
	Preoperative IOPA	Postoperative IOPA	Preoperative CBCT	Postoperative CBCT
Normal	4.0	79.2	4.2	69.0
Small changes in bone	18.0	16.7	18.8	26.2
Changes in bone structures and mineral loss	14.0	4.2	12.5	4.8
Apical periodontitis with well defined radiolucency	44.0	-	43.8	-
Large radiolucent area	20.0	-	20.8	-

PAI: Periapical index, IOPA: Intraoral periapical, CBCT: Cone-beam computed tomography

Figure 3. Periapical index score in pre- and postoperative intraoral periapical and cone-beam computed tomography

Two-dimensional radiograph analysis

Forty-eight teeth had their RL and RRA shifts assessed on 2D periapical radiographs **(Table 3)**. The paired t-test comparison of preoperative and postoperative measurements revealed a substantial lengthening: average RL increased from 11.30 ± 1.9 mm before therapy to 13.02 ± 1.2 mm at follow-up. The mean percentage gain in RL was 14.16 ± 7.4. Likewise, a marked overall increase in RRA was documented, climbing from a preoperative average of 33.54 ± 10.08 mm^2 to a postoperative average of 48.25 ± 13.9 mm^2.

Table 4. Dentin volume change measured at 12-month follow-up with cone beam computed tomography imaging

Parameter	Minimum	Mean	Maximum	Standard deviation
Preoperative CBCT volume	109.8	284.4107	443.8	68.5045
Follow-up CBCT volume	175.5	366.3905	525.5	72.98896
Increase in dentin volume	22	71.0365	166.1	31.10077
Percentage change in volume	6.04	26.6319	132.7	20.40847

Volume change (3D analysis with CBCT): Thirty-nine paired preoperative-postoperative CBCT data sets were obtainable for the 3D dentin volume analysis conducted within ITK SNAP. Processing these 39 matched samples revealed a mean volumetric increment of 26.63 ± 20.4 **(Table 4)**.

Patient-centered outcomes

Survival

Among the 49 cases reassessed, 48 teeth (98%) survived, with an average observation period of 14.26 months. The patients retained these dentitions throughout the designated review interval; upon inspection, the teeth were found intact, healthy, and symptom-free, with no additional therapeutic procedures deemed necessary.

Discoloration

Both the chromatic alteration attributable to the initial traumatic incident and the TAP-mediated staining were counteracted by internal bleaching. Patient satisfaction with the esthetic result was high, and the corrected shade remained stable at all subsequent recall examinations.

Two therapeutic pathways exist for managing an immature tooth afflicted by pulp necrosis and apical periodontitis: apexification and regenerative endodontic treatment (RET). Documented clinical success figures stand at 89.7% for RETs and reach 100% for apexification/apical barrier procedures [14, 15]. The materials employed to achieve apexification span calcium hydroxide, MTA, and Biodentine. Although both calcium hydroxide and MTA apexification yield favorable results, their respective shortcomings relative to biodentine include the lengthy, uncertain timeframe required to create an apical barrier with calcium hydroxide, as well as the extended setting time and suboptimal handling characteristics of MTA [16-18].

Evidence suggests that the capacity for root maturation within immature necrotic teeth hinges on the functional integrity of Hertwig's epithelial sheath [19]. Insult from the original injury and/or a prolonged infectious state may compromise both Hertwig's epithelial root sheath (HERS) and the pulpal precursor cell population, culminating in unsuccessful regenerative therapy and an absence of root elongation post-RET [20-22]. In the context of the current investigation, however, the likelihood of favorable root maturation via revascularization for incisors where trauma constituted the initiating event remains undetermined.

The foremost consideration guiding treatment selection is the individual's age. The recommended age range for RET is 8 to 18 years [23]. Over 60% of participants enrolled in this study exceeded the upper boundary of that recommendation. A further consideration is the delay between the traumatic episode and clinical attendance. An extended period of pulp necrosis exceeding 6 months has been linked to diminished root maturation quality following RET [24]. Every case included in this study involved pulp necrosis of greater than 6 months' duration, making the ongoing viability of Hertwig's epithelial sheath highly improbable. Under such circumstances, a regenerative procedure might register as a clinical success yet simultaneously represent a biological failure. Accordingly, biodentine apexification constituted the appropriate treatment strategy for the cases recruited herein.

Eradication of the necrotic pulp tissue, accompanied by thorough disinfection of the canal system, is a fundamental prerequisite underpinning the success of any endodontic procedure. TAP, formulated from ciprofloxacin, metronidazole, and minocycline, was first described in Sato *et al*. [25]. The advocated recipe for TAP combines metronidazole (500 mg), minocycline (100 mg), and ciprofloxacin (200 mg) in equal 1:1:1 proportions [26]. The vehicle comprises propylene glycol blended with macrogol ointment, also at a 1:1 ratio [26]. This particular mixture is effective at eradicating viable microbial flora from infected root canal spaces, fostering the gradual resolution of periapical radiolucencies, generating meaningful thickening of the canal walls, and stimulating regeneration within the periapical tissue compartment [26, 27]. Guided by this rationale, every tooth in the present study received an inter-appointment dressing of freshly compounded TAP (1:1:1 ratio) mixed with propylene glycol for 15 days preceding canal obturation.

Given that instrumentation within immature canals carries the potential to disrupt root maturation, a restrained approach to canal shaping using manual K-files was adopted in this study, followed by lavage with a saline and povidone-iodine solution [28]. Disruption to the periapical tissue bed must be prevented when instrumenting immature canals, so that the surviving elements of HERS, operating within a conducive environment, may orchestrate the differentiation of apical mesodermal tissue into root constituents [29-31]. Moreover, it is firmly established that calcium silicate cements can activate stem cells residing in the apical papilla, along with associated signaling molecules, directing them toward specific differentiation cascades and thereby inducing apical closure by precipitating apatite on the root cement surface [32]. Drawing on these principles, the authors concluded that the biodentine used in this study could stimulate collagen fiber formation and fibroblast proliferation, thereby yielding gains in RL, RRA, and root dentin.

Owing to its outstanding sealing capacity and biological compatibility, Biodentine was selected as the apexification agent in this study. Biodentine exhibits a markedly shorter setting time than MTA. It demonstrates biocompatibility when placed in contact with connective tissue [33]. Furthermore, it enhances the fracture resistance of immature teeth when deployed as an apical plug [34]. A configuration in which the root canals are obturated with Gutta-Percha and the clinical crowns are rebuilt with composite restorations atop a biodentine plug results in a more favorable stress distribution, thereby lessening strain concentration at the mid-coronal root zone [34].

Quantitative methodologies for gauging radiographic root alterations following endodontic intervention in immature teeth using 2D datasets have undergone long-term development and validation [11, 27]. Chen *et al*. [19] performed a qualitative scoring of periapical lesion healing in immature permanent teeth presenting with infected necrotic pulp tissue and apical periodontitis/abscess. In this study, the PAI scoring system was chosen to assess periapical status and healing trajectory, as it is the most appropriate validated tool available in endodontics. A CBCT-derived PAI score has likewise been evaluated and validated, and this metric was incorporated into the present work, confirming that periapical repair was discernible across all teeth. Individuals in the younger age stratum exhibited complete resolution of periapical pathology, whereas those in the older age stratum did not. Where preoperative periapical radiolucencies were extensive, healing was still actively progressing. Taken together, 79.2% of lesions were fully resolved at the 12-month evaluation point, and 20.8% of teeth were undergoing active resolution. No instance of persistent or expanding radiolucency was recorded among participants.

Pretreatment and posttreatment radiographs were processed using ImageJ (National Institutes of Health, Bethesda, MD), with the TurboReg plugin (Lausanne, VD, Switzerland) used to correct geometric discrepancies in projection angle for RL quantification mathematically [6, 27]. RL was determined along a linear path from the cementoenamel junction to the root apex. Radiographic evidence confirming the establishment of a hard tissue barrier was observed in all immature permanent teeth subjected to the Biodentine apexification protocol. A statistically significant elongation of RL was recorded, yielding a mean RL increase of 14.17% ± 7.4%.

The RRA measurement technique, developed and validated by Flake *et al*. [11], enables radiographic quantification of changes in root dimensions following endodontic treatment of immature teeth. This measurement protocol was applied in the present study. On the recall radiographs, the Biodentine apical barrier—accompanied or not by visible Gutta-Percha—was registered as root area, whereas the radiolucent canal space was designated as root canal. A statistically significant expansion in RRA was documented.

Three-dimensional volumetric analysis of root maturation using CBCT data represents a recent methodological advancement that provides a more robust assessment tool and deeper insight into the spatial patterns of hard-tissue deposition [7, 13]. The integration of standardized 2D information with 3D datasets could supply critically needed data regarding treatment outcomes for immature teeth [35]. In the current investigation, 3D volumetric quantification of root dentin, performed using CBCT scans, demonstrated an average volume augmentation of 26.63%, suggesting that biodentine apexification can achieve hard-tissue deposition across three spatial planes. Our study presents the first detailed 3D analysis of dentine volumetric shifts in the context of biodentine apexification procedures.

A systematic review concluded that there is no meaningful difference between RET and MTA apical plug approaches in terms of survival or success rates when managing immature teeth with necrotic pulps [36]. Patient-centered outcomes encompass the presence of healthy, structurally sound teeth in the oral cavity and their aesthetic contribution. Our findings documented a 98% survival figure.

Tooth staining is a notable disadvantage that often occurs after minocycline is incorporated into TAP preparations. Yet, TAP-induced discoloration has been effectively corrected through internal bleaching interventions [37]. In this present study, both the chromatic change stemming from the trauma itself and the discoloration induced by TAP were addressed via internal bleaching. Patients reported satisfaction with the whitening results, and the color correction remained stable at follow-up assessments.

This investigation of the biodentine apexification protocol applied to traumatically injured teeth revealed that this highly bioactive, maximally biocompatible calcium-based cement is an efficacious agent for apexification and can regenerate damaged dental structures. While this study demonstrated favorable outcomes with biodentine apexification, the modest participant numbers were insufficient to permit a deeper analysis that could disentangle the effects of variables—namely, patient age, apical foramen diameter, root developmental stage, and extended observation durations for TAP-related discoloration—on the dependent measures.

Conclusion

The current investigation established that biodentine apexification applied to traumatized maxillary incisors featuring necrotic pulps and open apices produced favorable clinical and radiographic results accompanied by outstanding periapical repair. The outcomes evidenced significant gains in RL, RRA, and dentin volume. Three-dimensional volume analysis indicates that biodentine apexification can deposit hard tissue in all three spatial dimensions. Consequently, it stands as an effective material for apexification procedures.

Acknowledgments: None

Conflict of Interest: None

Financial Support: None

Ethics Statement: None

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