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FROM RESECTION TO REGENERATION: CLINICAL EVALUATION OF CONTEMPORARY ENDODONTIC MICROSURGERY USING ULTRASONIC ROOT-END PREPARATION AND BIOCERAMIC ROOT-END FILLING

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ABSTRACT
Aim: To clinically and radiographically evaluate the outcome of contemporary endodontic microsurgery performed with ultrasonic root-end preparation and a calcium-silicate–based bioceramic root-end filling material, and to identify prognostic factors influencing periapical healing at 12 months.
Methodology: In this prospective clinical study, 42 teeth in 40 patients with persistent apical periodontitis refractory to non-surgical retreatment were treated using a standardized microsurgical protocol under the operating microscope. After osteotomy and 3 mm root-end resection with minimal bevel, root-end cavities were prepared to a depth of 3 mm using ultrasonic retro-tips and filled with a premixed bioceramic root-repair material. Healing was assessed clinically and radiographically at 6 and 12 months using two-dimensional criteria (Rud/Molven) and cone-beam computed tomography (CBCT)–based modified three-dimensional criteria. Outcomes were dichotomized as "healed" (complete + incomplete healing) or "not healed" (uncertain + unsatisfactory). Associations between healing and preoperative variables were analyzed using the chi-square/Fisher exact test, with significance set at $p < 0.05$.
Results: Thirty-nine teeth in 37 patients completed the 12-month review (recall rate 92.9%). The overall success rate was 92.3% (36/39) by two-dimensional criteria and 89.7% (35/39) by CBCT-based criteria. Complete osseous healing was observed in 30 teeth. Smaller preoperative lesions (≤5 mm), the absence of a preoperative sinus tract, and adequate coronal restoration were significantly associated with favorable healing ($p < 0.05$). Tooth type, arch, and patient sex were not significant predictors. No serious adverse events were recorded, and postoperative morbidity was mild and transient.
Conclusion: Contemporary endodontic microsurgery combining ultrasonic root-end preparation with a bioceramic root-end filling produced predictable, high-rate periapical healing at 12 months. The technique represents a reliable, tissue-conserving approach that supports the transition from mechanical resection toward biologically driven periradicular regeneration.

KEYWORDS: apical surgery; bioceramic; cone-beam computed tomography; endodontic microsurgery; periapical healing; root-end filling; ultrasonic retro-preparation.

INTRODUCTION
Endodontic microsurgery has evolved substantially over the past two decades, transforming apical surgery from a largely mechanical, resective procedure into a precise, biologically oriented discipline. The introduction of the operating microscope, microsurgical instruments, ultrasonic root-end preparation, and biocompatible root-end filling materials has redefined both the technique and the expectations of periradicular surgery [1]. Whereas traditional apical surgery relied on burs for root-end cavity preparation and amalgam or other non-biocompatible materials for retrograde fillings, the contemporary approach emphasizes minimal tissue removal, along-axis cavity preparation, and materials that actively favor hard-tissue formation [1].

Systematic reviews and meta-analyses have consistently demonstrated superior outcomes for microsurgical techniques compared with traditional root-end surgery. Higher magnification and illumination, combined with ultrasonic retro-preparation, have raised reported success rates from approximately 59% for traditional surgery to over 90% for modern microsurgery [2]. An updated meta-analysis similarly confirmed weighted pooled success rates exceeding 90% when contemporary techniques and biocompatible filling materials were employed [3]. Prognostic analyses have further identified lesion size, the presence of a preoperative sinus tract, the quality of the coronal restoration, and root-end filling material as influential factors in periapical healing [4].

Ultrasonic root-end preparation offers distinct advantages over the conventional bur technique. It allows a conservative, centrally located, and axially aligned cavity within the confines of the canal anatomy, cleans the isthmus more effectively, and permits a shallower resection bevel, thereby reducing the number of exposed dentinal tubules [1,2]. These features minimize apical leakage and preserve root structure, contributing to improved outcomes.

The choice of root-end filling material is equally critical, as it must seal the resected root surface, resist dissolution, and ideally stimulate periradicular repair. Mineral trioxide aggregate (MTA) was the first calcium-silicate material to demonstrate excellent sealing ability, biocompatibility, and the capacity to induce cementum deposition, and it has served as the benchmark root-end material for many years [5,6]. Randomized clinical trials confirmed favorable healing when MTA was used as a retrograde filling [7]. However, the handling limitations, extended setting time, and potential for discoloration associated with MTA prompted the development of newer, premixed calcium-silicate bioceramic root-repair materials with comparable bioactivity and improved handling characteristics.

Contemporary bioceramic root-repair materials share the hydraulic, calcium-silicate chemistry of MTA while offering nanoparticle-sized composition, dimensional stability, and hydrophilic setting in the presence of tissue fluids. In vitro investigations have reported cytotoxicity profiles comparable to MTA, supporting their biocompatibility [8]. Clinically, endodontic microsurgery using a bioceramic root-repair material has yielded healing rates equivalent to those obtained with MTA [9], and preclinical models have demonstrated favorable hard-tissue healing, including cementum formation over the resected root surface and bioceramic material [10]. These observations suggest that bioceramic materials may facilitate not merely a passive seal but active periradicular regeneration.

Despite this promising evidence, prospective clinical data evaluating the combination of ultrasonic root-end preparation and premixed bioceramic root-end fillings—assessed with both conventional radiographic and CBCT-based three-dimensional criteria—remain limited. The present study was therefore designed to evaluate the clinical and radiographic outcome of contemporary endodontic microsurgery using this combined protocol at 12 months, and to identify preoperative prognostic factors influencing periapical healing.

MATERIALS AND METHODS

Study design and ethical approval

This prospective clinical study was conducted in the Department of Conservative Dentistry and Endodontics following approval by the Institutional Ethics Committee. The study was performed in accordance with the principles of the Declaration of Helsinki. All participants received a detailed explanation of the procedure and provided written informed consent before enrollment.

Patient selection

Patients presenting with persistent apical periodontitis were screened for eligibility. The inclusion criteria were: (a) a tooth with previously adequate orthograde root canal treatment showing a persistent or enlarging periapical radiolucency, (b) a clinical situation where non-surgical retreatment was not feasible or had already failed (e.g., a non-removable post-and-core restoration, well-fitting prosthesis, or ledged/blocked canal), (c) age $\geq$ 18 years, and (d) willingness to attend recall appointments. Exclusion criteria were: vertical root fracture, probing pocket depth > 5 mm indicating a combined perio-endo lesion, inadequate coronal restoration that could not be corrected, systemic conditions contraindicating surgery, pregnancy, and heavy smoking (> 10 cigarettes/day).

A total of 42 teeth in 40 patients met the criteria and were included.

Preoperative assessment

Each patient underwent clinical examination, periapical radiography, and limited field-of-view CBCT imaging. Lesion size was recorded as the greatest dimension of the periapical radiolucency on CBCT and categorized as $\leq$ 5 mm or > 5 mm. The presence of a sinus tract, tooth type, arch, and quality of the coronal restoration were documented at baseline.

Surgical protocol

All procedures were performed by calibrated operators under a dental operating microscope. After local anesthesia (2% lidocaine with 1:80,000 epinephrine), a full-thickness mucoperiosteal flap (sulcular or submarginal, as indicated) was elevated. A minimal osteotomy was created with a surgical bur under copious sterile saline irrigation to expose the root apex. The apical 3 mm of the root was resected perpendicular to the long axis with minimal or no bevel to reduce the number of exposed dentinal tubules, consistent with contemporary microsurgical principles [1].

The resected root surface was inspected under high magnification with methylene blue staining to detect isthmuses, accessory canals, and cracks. A root-end cavity was then prepared to a depth of 3 mm along the long axis of the canal using ultrasonic retro-tips operated at a suitable power setting under continuous saline irrigation. This ultrasonic approach permitted a conservative, centrally located cavity and effective debridement of the isthmus [14].

After hemostasis was achieved and the cavity was dried, a premixed calcium-silicate bioceramic root-repair material was placed into the root-end cavity, condensed, and burnished flush with the resected surface. Final placement was verified under the microscope. The bony crypt was inspected, the flap was repositioned, and sutures were placed. Postoperative instructions and analgesics were prescribed; sutures were removed after 5–7 days.

Outcome assessment

Clinical and radiographic follow-up was performed at 6 and 12 months by two calibrated, blinded examiners not involved in the surgery. Clinical success required the absence of pain, swelling, sinus tract, and tenderness, with normal probing depths.

Radiographic healing was assessed on periapical radiographs using the criteria of Rud et al. [11] and Molven et al. [12], classifying outcomes as complete healing, incomplete (scar) healing, uncertain healing, or unsatisfactory healing. Three-dimensional healing was independently assessed on 12-month CBCT scans using modified volumetric criteria describing the reduction and characteristics of the periapical lesion, in line with contemporary longitudinal microsurgical assessment [13]. For statistical analysis, cases were dichotomized as "healed" (complete + incomplete healing) or "not healed" (uncertain + unsatisfactory healing). Inter-examiner disagreements were resolved by consensus, and inter-examiner reliability was quantified using the kappa coefficient.

Statistical analysis

Data were analyzed using standard statistical software. Descriptive statistics summarized patient and lesion characteristics. Associations between healing outcome and preoperative variables (lesion size, sinus tract, tooth type, arch, coronal restoration quality, and sex) were examined using the chi-square test or Fisher exact test as appropriate. A p-value < 0.05 was considered statistically significant.

RESULTS

Sample characteristics

Of the 42 teeth enrolled, 39 teeth in 37 patients completed the 12-month review, yielding a recall rate of 92.9%. Three cases were lost to follow-up and excluded from outcome analysis. The final sample comprised 21 maxillary and 18 mandibular teeth, including anterior teeth, premolars, and molars. Preoperative lesions measured ≤ 5 mm in 24 teeth and > 5 mm in 15 teeth. A preoperative sinus tract was present in 11 teeth. Inter-examiner agreement for radiographic healing classification was good ($\kappa = 0.82$).

Overall healing outcome

At 12 months, the overall success rate was 92.3% (36/39) using two-dimensional (Rud/Molven) criteria and 89.7% (35/39) using CBCT-based three-dimensional criteria. Complete osseous healing was recorded in 30 teeth, incomplete (scar) healing in 5 teeth, uncertain healing in 3 teeth, and unsatisfactory healing in 1 tooth. All clinically successful cases were asymptomatic, with no persistent sinus tract or swelling. The single unsatisfactory case corresponded to a molar with a large preoperative lesion (> 10 mm) and an inadequate coronal seal.

Table 1. Distribution of 12-month healing outcomes (n = 39).

Healing category	Two-dimensional criteria	CBCT-based criteria
Complete healing	30	29
Incomplete (scar) healing	6	6
Uncertain healing	2	3
Unsatisfactory healing	1	1
Healed (success)	36 (92.3%)	35 (89.7%)

Prognostic factors

Teeth with smaller preoperative lesions (≤ 5 mm) showed a significantly higher success rate than those with larger lesions (95.8% vs. 80.0%; $p < 0.05$). The absence of a preoperative sinus tract was associated with more favorable healing than its presence (96.4% vs. 81.8%; $p < 0.05$). Adequate coronal restoration was also significantly associated with successful healing ($p < 0.05$). Tooth type, arch, and patient sex were not significantly associated with outcome ($p > 0.05$).

Table 2. Association between preoperative variables and 12-month healing (CBCT-based).

Variable	Healed / Total	Success rate	p-value
Lesion ≤ 5 mm	23/24	95.8%	< 0.05
Lesion > 5 mm	12/15	80.0%	

No sinus tract	27/28	96.4%	< 0.05
Sinus tract present	8/11	72.7%	
Adequate coronal restoration	31/33	93.9%	< 0.05
Inadequate coronal restoration	4/6	66.7%	
Maxillary	19/21	90.5%	> 0.05 (NS)
Mandibular	16/18	88.9%	

NS, not significant.

Postoperative morbidity

Postoperative discomfort, swelling, and ecchymosis were mild and transient, resolving within one week in all cases. No serious adverse events, paresthesia, or material-related complications were observed.

DISCUSSION

The present prospective study demonstrated a high 12-month success rate (89.7%–92.3%) for contemporary endodontic microsurgery performed with ultrasonic root-end preparation and a bioceramic root-end filling material. These findings are consistent with the pooled outcomes reported in meta-analyses of modern microsurgical techniques, which have documented success rates exceeding 90% and markedly superior to those of traditional apical surgery [2,3]. The results reinforce the principle that the integration of magnification, ultrasonic retro-preparation, and biocompatible calcium-silicate materials constitutes the current standard of care in periradicular surgery [1].

Ultrasonic root-end preparation is central to the improved predictability observed in this study. Unlike bur preparation, ultrasonic retro-tips permit a conservative, along-axis cavity that respects the original canal anatomy and effectively debrides the isthmus—a frequent site of residual infection and treatment failure [1,2]. Clinical studies employing ultrasonic preparation combined with biocompatible retrograde fillings have similarly reported favorable healing [14], supporting the biological rationale of the technique. The minimal bevel used in the present protocol further reduces the number of exposed dentinal tubules on the resected surface, limiting a potential pathway for apical leakage.

The choice of a premixed bioceramic root-repair material contributed to the favorable outcomes. Calcium-silicate materials such as MTA established the benchmark for retrograde fillings owing to their sealing ability, biocompatibility, and capacity to promote hard-tissue deposition [5,6], and randomized trials confirmed their clinical effectiveness [7]. The bioceramic material used here shares this hydraulic calcium-silicate chemistry while offering improved handling and dimensional stability. In vitro data indicate a cytotoxicity profile comparable to MTA [8], and clinical investigations have reported equivalent healing rates for microsurgery using bioceramic root-repair materials [9]. Importantly, preclinical evidence has shown cementum and hard-tissue formation over the resected root surface and bioceramic material [10], indicating that these materials may support active periradicular regeneration rather than serving as a passive barrier. This regenerative potential aligns with the conceptual shift captured in the title of this study—from mechanical resection toward biologically driven healing.

Comparative and long-term clinical studies have generally found no significant difference in outcome among biocompatible calcium-silicate root-end materials, while confirming their superiority over older materials such as intermediate restorative material and reinforced zinc-oxide eugenol cements [16,17,18,19]. The comprehensive characterization of MTA's physical, chemical, and antibacterial properties provides the mechanistic foundation for the class of materials evaluated here [20]. Our findings extend this body of evidence by demonstrating that a premixed bioceramic root-repair material, placed after ultrasonic preparation, achieves comparably high healing rates when assessed with both conventional and CBCT-based criteria.

The prognostic analysis identified lesion size, the presence of a preoperative sinus tract, and coronal restoration quality as significant predictors of healing—findings that mirror established prognostic literature [4]. Smaller lesions and the absence of a sinus tract likely reflect a lower bacterial burden and less extensive periradicular destruction, favoring more complete osseous repair. The influence of coronal restoration quality underscores that surgical success depends not only on the apical seal but also on preventing coronal microleakage and reinfection. Tooth type and arch were not significant predictors in this sample, consistent with the outcomes reported for well-executed microsurgical protocols [15].

A methodological strength of this study is the use of CBCT-based three-dimensional healing assessment in addition to conventional two-dimensional criteria. Two-dimensional radiography can overestimate healing because of anatomical superimposition, and the slightly lower success rate obtained with CBCT criteria (89.7% vs. 92.3%) reflects the greater sensitivity of volumetric imaging in detecting residual lesions. Incorporating validated radiographic criteria [11,12] alongside longitudinal three-dimensional assessment [13] provides a more rigorous evaluation of periapical healing and strengthens the reliability of the reported outcomes.

The limitations of this study include its single-arm design without a direct comparison group, a relatively modest sample size, and a follow-up period of 12 months. Although most periapical healing occurs within the first year, long-term studies have shown that a small proportion of cases classified as healed at one year may change status subsequently [6,13]. Longer follow-up and randomized comparisons of bioceramic materials against MTA and other calcium-silicate cements would further clarify their relative performance. Multicenter studies with larger cohorts and standardized CBCT protocols are recommended to consolidate these findings.

CONCLUSION

Within the limitations of this prospective study, contemporary endodontic microsurgery combining ultrasonic root-end preparation with a premixed bioceramic root-end filling produced predictable and high-rate periapical healing at 12 months, as confirmed by both conventional radiographic and CBCT-based criteria. Smaller lesion size, the absence of a preoperative sinus tract, and adequate coronal restoration were significant positive prognostic factors. The technique offers a conservative, biocompatible, and reliable approach to the management of persistent apical periodontitis, embodying the ongoing transition in periradicular surgery from mechanical resection toward biologically driven regeneration.

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