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Original Article

Comparing Treatment Outcomes Using Digital Periapical Radiographs Against Cone-Beam CT for Managing Complex Root Canal Cases

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ABSTRACT

Background: Accurate retreatment of failed root canal cases requires reliable identification of complex canal anatomy and persistent periapical pathology. Digital periapical radiographs are routinely used but provide limited two-dimensional information, whereas cone-beam computed tomography offers three-dimensional visualization that may improve retreatment planning. Objective: To compare clinical and radiographic outcomes of cone-beam computed tomography-guided retreatment with digital periapical radiograph-guided retreatment in previously failed root canal cases. Methods: A parallel-group randomized controlled trial was conducted among 72 adults requiring nonsurgical endodontic retreatment. Participants were allocated equally to cone-beam computed tomography-guided planning or digital periapical radiograph-guided planning. Standardized retreatment procedures were performed in both groups. Outcomes were assessed at baseline and four weeks. The primary outcome was radiographic healing measured by periapical index score, while secondary outcomes included visual analog scale pain score and tenderness to percussion. Results: Sixty-five participants completed follow-up, including 33 in the cone-beam computed tomography group and 32 in the periapical radiograph group. The cone-beam computed tomography group showed significantly lower four-week periapical index scores than the control group (1.8 ± 0.6 vs 2.4 ± 0.7; mean difference -0.6, 95% CI -0.9 to -0.3; p=0.001). Pain scores were also lower (1.9 ± 0.8 vs 2.8 ± 0.9; p=0.002), and tenderness was less frequent (15.2% vs 34.4%; p=0.048). Conclusion: Cone-beam computed tomography-guided retreatment improved short-term radiographic healing and clinical recovery compared with periapical radiograph-guided planning, supporting selective use in complex endodontic retreatment. Keywords: Cone-Beam Computed Tomography; Endodontics; Periapical Diseases; Radiography, Dental; Root Canal Therapy; Treatment Outcome.

INTRODUCTION

Successful endodontic retreatment depends on accurate identification of the biological and technical causes of previous treatment failure, followed by precise removal of infected material, negotiation of untreated or inadequately treated canals, effective chemomechanical disinfection, and durable obturation of the root canal system. Although primary root canal therapy has high success potential when performed under optimal conditions, persistent or recurrent apical periodontitis remains a clinically important problem, particularly in teeth with missed canals, complex canal morphology, inadequate previous obturation, procedural errors, or persistent microbial infection within inaccessible anatomical spaces (1). In retreatment cases, diagnostic accuracy becomes especially important because the clinician must not only confirm the presence of disease but also identify the underlying reason for failure and determine whether nonsurgical retreatment is likely to achieve healing.

Digital periapical radiography remains the most widely used imaging modality in endodontic diagnosis and follow-up because it is accessible, cost-effective, familiar to clinicians, and associated with relatively low radiation exposure. However, periapical radiographs provide a two-dimensional representation of three-dimensional dental and periapical structures, making them vulnerable to anatomical superimposition, geometric distortion, and reduced sensitivity for detecting early or complex periapical lesions. These limitations are particularly relevant in previously treated teeth, where radiopaque filling materials, post-endodontic restorations, overlapping roots, and altered canal anatomy may obscure clinically important findings. As a result, reliance on periapical radiography alone may underestimate lesion extent, fail to detect missed canals, or provide insufficient information for retreatment planning in complex cases (2,3).

Cone-beam computed tomography has expanded the diagnostic capacity of endodontics by enabling three-dimensional visualization of root canal anatomy, periapical pathology, resorptive defects, root fractures, and procedural complications. Compared with conventional periapical radiography, cone-beam computed tomography can improve detection of periapical lesions and clarify anatomical variations that may influence treatment planning. This diagnostic advantage is particularly relevant for endodontic retreatment, where clinical success may depend on identifying untreated canals, recognizing the true spatial extent of periapical disease, and detecting factors that may alter the feasibility or strategy of nonsurgical management (4,5).

Despite this diagnostic superiority, the clinical value of cone-beam computed tomography cannot be assumed solely from its imaging performance. Improved visualization is meaningful only if it changes clinical decision-making and translates into better patient outcomes, such as greater periapical healing, reduced postoperative pain, and resolution of clinical signs. Existing literature has largely emphasized diagnostic accuracy, treatment planning influence, or retrospective outcome assessment, while comparatively fewer controlled clinical studies have directly evaluated whether cone-beam computed tomography-guided retreatment produces superior short-term clinical and radiographic outcomes compared with retreatment planned using digital periapical radiographs (6,7). This distinction between diagnostic accuracy and therapeutic effectiveness represents a key evidence gap.

The justification for selective cone-beam computed tomography use must also be balanced against radiation exposure, cost, availability, and the requirement for appropriate interpretation. Although three-dimensional imaging may provide substantial benefit in complex retreatment cases, indiscriminate use is not consistent with radiation protection principles. Therefore, outcome-based evidence is needed to determine whether cone-beam computed tomography offers sufficient clinical advantage in complex failed root canal cases to justify its selective incorporation into retreatment protocols. Such evidence is especially important in resource-sensitive clinical settings, where advanced imaging should be reserved for situations in which it meaningfully improves diagnostic confidence, treatment precision, and patient-centered outcomes (8,9).

The present randomized controlled trial was designed to address this gap by comparing retreatment outcomes in previously failed root canal cases planned using cone-beam computed tomography versus digital periapical radiographs. The primary focus was radiographic healing assessed by periapical index score, while secondary outcomes included pain intensity and tenderness to percussion. The study hypothesized that cone-beam computed tomography-guided retreatment would produce greater reduction in periapical index scores and better clinical symptom resolution than retreatment guided by digital periapical radiography alone.

MATERIALS AND METHODS

This study was conducted as a parallel-group randomized controlled trial to compare the effectiveness of cone-beam computed tomography-guided retreatment planning with digital periapical radiograph-guided planning in patients requiring nonsurgical endodontic retreatment of previously failed root canal-treated teeth. The trial was carried out in tertiary dental care settings in the Urban Region of Sindh over a total period of five months, including participant screening, recruitment, allocation, intervention delivery, and follow-up assessment. For each enrolled participant, the clinical intervention and outcome evaluation were completed over a four-week period, allowing standardized short-term comparison of radiographic and clinical responses following retreatment.

Adult patients aged 18–60 years who presented with previously root canal-treated teeth showing persistent periapical pathology and requiring nonsurgical endodontic retreatment were considered eligible. Teeth were included when they had adequate coronal restorability and were clinically suitable for conservative retreatment. Patients were excluded if they were pregnant, had uncontrolled systemic conditions likely to impair healing such as uncontrolled diabetes mellitus, presented with teeth having suspected or confirmed vertical root fracture, had advanced periodontal disease affecting prognosis, or required surgical endodontic intervention rather than nonsurgical retreatment. Participants were recruited consecutively from eligible patients attending the dental care centers during the study period. Written informed consent was obtained before enrolment after explaining the study purpose, procedures, imaging approach, possible benefits, and radiation-related considerations.

A total of 72 participants were enrolled and randomly assigned in a 1:1 ratio to either the cone-beam computed tomography-guided intervention group or the digital periapical radiograph-guided control group. Randomization was performed using a computer-generated sequence prepared by an independent researcher who was not involved in recruitment, clinical treatment, or outcome assessment. Allocation concealment was maintained using sequentially numbered, sealed, opaque envelopes that were opened only after the participant had been enrolled. Due to the visible and procedural differences between imaging modalities, operator blinding was not feasible; however, outcome assessment was performed by a blinded evaluator who was unaware of group allocation to reduce assessment bias.

Participants allocated to the intervention group underwent cone-beam computed tomography imaging before retreatment planning. The CBCT assessment was used to evaluate canal morphology, missed canals, periapical lesion extent, previous obturation quality, root configuration, and possible complications affecting retreatment strategy. Participants in the control group underwent retreatment planning using digital periapical radiographs alone. In both groups, retreatment was performed according to the same standardized clinical protocol by experienced endodontists. The procedure included removal of previous obturation material, canal negotiation, working-length determination, chemomechanical preparation, irrigation, intracanal disinfection as clinically indicated, and final obturation using a warm vertical compaction technique. Standardization of treatment procedures across both groups was used to minimize performance variability and ensure that the primary distinction between groups remained the imaging modality used for treatment planning.

The primary outcome was radiographic healing measured through change in periapical index score from baseline to four weeks after retreatment. Secondary outcomes included pain intensity measured using the visual analog scale and clinical tenderness to percussion assessed at follow-up. Baseline demographic and clinical variables included age, sex, baseline pain score, and baseline periapical index score. Pain was operationally defined as patient-reported intensity on the visual analog scale, while tenderness to percussion was recorded as present or absent during clinical examination. Radiographic healing was operationally defined as reduction in periapical index score between baseline and post-intervention assessment. Follow-up adherence was supported through scheduled review visits and reminder calls.

To reduce bias, allocation concealment was implemented before group assignment, treatment procedures were standardized, and outcome assessment was blinded. Baseline comparability between groups was assessed using demographic and clinical variables. Missing outcome data due to loss to follow-up were managed using the last observation carried forward approach for intention-to-treat analysis, while final observed outcome summaries were reported for participants completing follow-up. Data integrity was supported through structured data collection forms, predefined variable coding, independent verification of entered data, and review of datasets before statistical analysis.

The sample size consisted of 72 participants, with 36 participants allocated to each group. This sample size was selected to provide sufficient group size for detecting clinically meaningful differences in short-term radiographic healing and pain outcomes between the two imaging-guided retreatment strategies, based on comparable interventional endodontic studies using radiographic and clinical endpoints. Statistical analysis was performed after assessment of data distribution using the Shapiro–Wilk test. Continuous variables were summarized as mean and standard deviation, while categorical variables were summarized as frequency and percentage. Independent-samples t-tests were used for between-group comparisons of continuous outcomes, and paired-samples t-tests were used for within-group pre–post comparisons. Repeated-measures analysis of variance was applied to evaluate time, group, and time-by-group interaction effects for periapical index change. Categorical outcomes such as tenderness to percussion were compared between groups using appropriate tests for proportions. Pearson correlation analysis was used to evaluate the relationship between reduction in periapical index score and pain reduction. Statistical significance was set at $p<0.05$.

The study was conducted in accordance with ethical principles for human participant research. Written informed consent was obtained from all participants, and patient confidentiality was maintained throughout data collection, analysis, and reporting. Imaging was performed only as required for the allocated diagnostic pathway, and the use of cone-beam computed tomography was restricted to the intervention group in line with the study objective and radiation-safety considerations.

RESULTS

A total of 94 patients were screened during the five-month study period, of whom 72 fulfilled the eligibility criteria and were randomized equally into the cone-beam computed tomography-guided intervention group (n=36) and the digital periapical radiograph-guided control group (n=36). Seven participants were lost to follow-up during the intervention and review period, including three from the intervention group and four from the control group. Final observed outcome analysis was therefore based on 65 participants, comprising 33 in the intervention group and 32 in the control group. Baseline demographic and clinical characteristics were analyzed for the full randomized sample and showed no statistically significant between-group differences, indicating adequate baseline comparability.

Table 1. Baseline Demographic and Clinical Characteristics of Randomized Participants (N=72)

Variable	Total Sample (N=72)	CBCT Group (n=36)	Periapical Radiograph Group (n=36)	Mean Difference / Difference in Proportion	p-value
Age, years	38.6 ± 9.4	39.1 ± 9.1	38.0 ± 9.8	1.1 years	0.62
Male sex, n (%)	40 (55.6%)	19 (52.8%)	21 (58.3%)	-5.5%	0.64
Baseline VAS pain score	6.8 ± 1.2	6.9 ± 1.1	6.7 ± 1.3	0.2 points	0.48
Baseline periapical index score	3.6 ± 0.7	3.7 ± 0.6	3.6 ± 0.7	0.1 points	0.55

CBCT: cone-beam computed tomography; VAS: visual analog scale. Values are presented as mean ± standard deviation unless otherwise stated.

At four weeks, the primary radiographic outcome favored the CBCT-guided group. The post-intervention periapical index score was significantly lower in the CBCT group than in the periapical radiograph group, with a mean difference of -0.6 points and a 95% confidence interval ranging from -0.9 to -0.3. This indicated greater short-term radiographic healing among patients whose retreatment planning was guided by three-dimensional imaging.

Table 2. Post-Intervention Between-Group Comparison of Primary Outcome (Final Observed Sample: n=65)

Outcome	CBCT Group (n=33)	Periapical Radiograph Group (n=32)	Mean Difference (95% CI)	p-value
Periapical index score at 4 weeks	**1.8 ± 0.6**	**2.4 ± 0.7**	**-0.6 (-0.9 to -0.3)**	**0.001**

CI: confidence interval. Within-group analysis demonstrated statistically significant improvement in periapical index scores in both treatment arms. However, the magnitude of improvement was greater in the CBCT group, where the mean periapical index score decreased from 3.7 ± 0.6 at baseline to 1.8 ± 0.6 at four weeks, compared with a reduction from 3.6 ± 0.7 to 2.4 ± 0.7 in the periapical radiograph group.

Table 3. Within-Group Pre–Post Change in Periapical Index Score

Group	Baseline PAI Score	4-Week PAI Score	Mean Change	p-value
CBCT group (n=33)	3.7 ± 0.6	1.8 ± 0.6	-1.9 ± 0.5	<0.001
Periapical radiograph group (n=32)	3.6 ± 0.7	2.4 ± 0.7	-1.2 ± 0.6	<0.001

PAI: periapical index. Repeated-measures analysis confirmed a significant overall time effect, group effect, and time-by-group interaction. The significant interaction indicated that the degree of improvement over time differed between the two groups, with greater radiographic improvement in the CBCT-guided intervention group.

Table 4. Repeated-Measures Analysis of Periapical Index Score

Effect	F-value	p-value
Time effect	152.4	<0.001
Group effect	11.2	0.001
Time × group interaction	9.6	0.003

Secondary clinical outcomes also favored the CBCT-guided group. At four weeks, the mean VAS pain score was 1.9 ± 0.8 in the CBCT group compared with 2.8 ± 0.9 in the periapical radiograph group, showing significantly lower residual pain in the intervention group. Tenderness to percussion was present in 5 participants (15.2%) in the CBCT group and 11 participants (34.4%) in the control group, indicating a lower frequency of persistent clinical tenderness after CBCT-guided retreatment.

Table 5. Secondary Clinical Outcomes at Four Weeks

Outcome	CBCT Group (n=33)	Periapical Radiograph Group (n=32)	Between Group Difference	p-value
VAS pain score	1.9 ± 0.8	2.8 ± 0.9	-0.9 points	0.002
Tenderness to percussion, n (%)	5 (15.2%)	11 (34.4%)	-19.2%	0.048

Correlation analysis demonstrated a moderate positive association between reduction in periapical index score and reduction in pain intensity (r=0.52, p<0.001), indicating that participants with greater radiographic improvement also tended to experience greater symptomatic relief.

Table 6. Association Between Radiographic Healing and Pain Reduction

Association Tested	Correlation Coefficient (r)	p-value
Reduction in periapical index score and reduction in VAS pain score	0.52	<0.001

Overall, the results showed that both imaging-guided retreatment strategies produced statistically significant short-term improvement, but CBCT-guided planning was associated with superior radiographic healing, lower residual pain, and reduced tenderness to percussion compared with retreatment planned using digital periapical radiographs alone.

Table 1 demonstrates that the randomized groups were clinically comparable at baseline. The mean age was 39.1 ± 9.1 years in the CBCT group and 38.0 ± 9.8 years in the periapical radiograph group, with a small mean difference of 1.1 years that was not statistically significant (p=0.62). Sex distribution was also balanced, with males comprising 52.8% of the CBCT group and 58.3% of the control group, showing only a 5.5% proportional difference (p=0.64). Baseline pain scores were similar between groups, with mean VAS values of 6.9 ± 1.1 and 6.7 ± 1.3, respectively (p=0.48), while baseline periapical index scores were also comparable at 3.7 ± 0.6 versus 3.6 ± 0.7 (p=0.55). These findings indicate that any post-intervention differences were unlikely to be explained by baseline imbalance in age, sex, pain severity, or radiographic disease burden.

Table 2 presents the primary post-intervention radiographic outcome and shows a statistically significant advantage for CBCT-guided retreatment. At four weeks, the mean periapical index score was 1.8 ± 0.6 in the CBCT group compared with 2.4 ± 0.7 in the periapical radiograph group, producing a mean difference of -0.6 points with a 95% confidence interval from -0.9 to -0.3 (p=0.001). The confidence interval did not cross zero, supporting both statistical significance and a clinically meaningful direction of effect favoring three-dimensional imaging-guided treatment planning.

Table 3 shows that both groups experienced significant within-group radiographic improvement after retreatment. In the CBCT group, the periapical index score decreased from 3.7 ± 0.6 at baseline to 1.8 ± 0.6 at four weeks, corresponding to a mean reduction of -1.9 ± 0.5 points (p<0.001). In the periapical radiograph group, the score decreased from 3.6 ± 0.7 to 2.4 ± 0.7, corresponding to a smaller mean reduction of -1.2 ± 0.6 points (p<0.001). Although both interventions were associated with healing, the absolute reduction was 0.7 points greater in the CBCT group, indicating stronger early radiographic recovery when retreatment planning incorporated three-dimensional assessment.

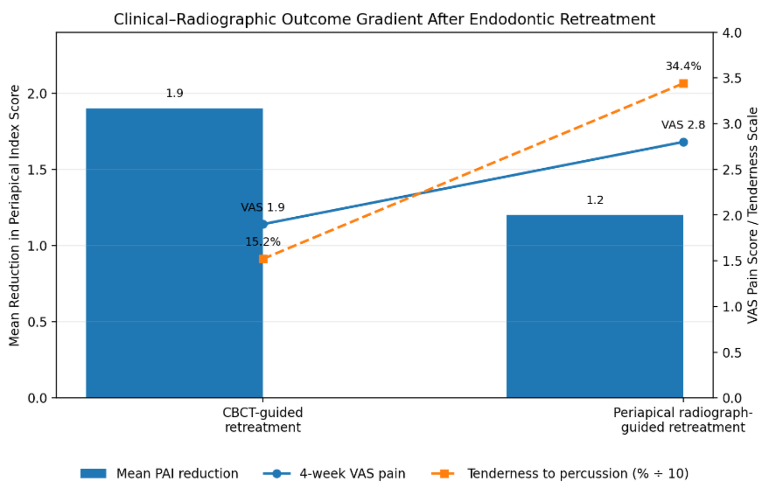

Figure 1 Clinical–Radiographic Outcome Gradient After Endodontic Retreatment

Table 4 confirms that the improvement pattern differed significantly between groups over time. The significant time effect (F=152.4, p<0.001) indicates that periapical index scores improved overall from baseline to follow-up. The significant group effect (F=11.2, p=0.001) indicates that the groups differed in overall outcome level, while the significant time × group interaction (F=9.6, p=0.003) demonstrates that the degree of improvement was not equivalent between groups. This interaction is particularly important because it supports the interpretation that CBCT-guided planning contributed to a greater trajectory of radiographic healing rather than merely reflecting baseline variation.

Table 5 summarizes the secondary clinical outcomes and shows that CBCT-guided retreatment was associated with better symptomatic recovery. The mean VAS pain score at four weeks was 1.9 ± 0.8 in the CBCT group compared with 2.8 ± 0.9 in the periapical radiograph group, yielding a between-group difference of -0.9 points (p=0.002). Tenderness to percussion persisted in 5 of 33 participants (15.2%) in the CBCT group compared with 11 of 32 participants (34.4%) in the control group, representing an absolute reduction of 19.2 percentage points in persistent tenderness (p=0.048). These findings suggest that the radiographic advantage of CBCT-guided planning was accompanied by clinically relevant reductions in pain and percussion sensitivity.

Table 6 demonstrates a moderate positive correlation between radiographic healing and pain reduction. The correlation coefficient of r=0.52 (p<0.001) indicates that participants with greater reduction in periapical index score also tended to show greater reduction in VAS pain intensity. This association supports the clinical coherence of the findings, as structural improvement in periapical status was moderately aligned with symptomatic recovery, although the relationship was not perfect, reflecting the multifactorial nature of post-retreatment pain and healing.

The figure 1 demonstrates a clinically coherent outcome gradient favoring CBCT-guided retreatment, where the mean periapical index reduction was greater in the CBCT group than in the periapical radiograph group (1.9 vs 1.2 points), while residual 4-week pain was lower (VAS 1.9 vs 2.8) and persistent tenderness to percussion was less frequent (15.2% vs 34.4%). This combined pattern indicates that greater radiographic healing aligned with better symptomatic recovery, supporting the reported moderate positive association between periapical index reduction and pain reduction (r=0.52, p<0.001).

DISCUSSION

The findings of the present randomized controlled trial demonstrated that retreatment of previously failed root canal cases guided by cone-beam computed tomography resulted in significantly greater short-term radiographic healing and improved clinical outcomes compared with retreatment planned using digital periapical radiographs. The greater reduction in periapical index scores observed in the CBCT group suggested that enhanced three-dimensional visualization allowed more accurate identification of missed canals, complex anatomical variations, and the true extent of periapical pathology, thereby facilitating more effective debridement and obturation. These results supported the hypothesis that improved diagnostic precision translates into measurable therapeutic benefit, particularly in complex retreatment scenarios where conventional imaging may underestimate disease burden (10).

The magnitude of radiographic improvement observed in this study was consistent with prior evidence demonstrating superior diagnostic performance of cone-beam computed tomography in detecting apical periodontitis, root fractures, and anatomical complexities. However, earlier studies have predominantly focused on diagnostic accuracy rather than clinical outcomes. The present findings extend this evidence by demonstrating that the additional diagnostic information obtained through three-dimensional imaging was associated with improved healing outcomes, thereby addressing a critical gap between imaging capability and clinical effectiveness. This supports the concept that advanced imaging is not merely a diagnostic adjunct but may influence treatment success when applied in appropriately selected cases (11,12).

The reduction in pain scores and lower incidence of tenderness to percussion in the CBCT-guided group further emphasized the clinical relevance of improved treatment planning. It is plausible that more accurate localization of infection and more complete canal debridement contributed to reduced postoperative inflammation and faster symptomatic resolution. The moderate positive correlation between reduction in periapical index score and pain reduction (r=0.52) suggested that radiographic healing and symptomatic improvement were interrelated, although not entirely overlapping, reflecting the multifactorial nature of endodontic outcomes where biological healing, host response, and procedural factors all contribute to recovery (13,14).

Despite these advantages, the findings must be interpreted within the broader context of radiation safety and resource utilization. Cone-beam computed tomography involves higher radiation exposure compared with conventional periapical radiography, and its use should therefore be justified based on clinical need. The results of this study support a selective application approach, where CBCT is reserved for cases with suspected complex anatomy, unclear pathology, or previous treatment failure that cannot be adequately evaluated using two-dimensional imaging. This aligns with current recommendations emphasizing judicious use of advanced imaging rather than routine application in all endodontic cases (15).

The study possesses several methodological strengths, including its randomized controlled design, allocation concealment, and blinded outcome assessment, which collectively reduce the risk of selection and assessment bias. The use of standardized treatment protocols across both groups minimized performance variability and ensured that differences in outcomes could be more confidently attributed to the imaging modality used for treatment planning. Additionally, the inclusion of both radiographic and clinical outcomes provided a more comprehensive assessment of treatment effectiveness, enhancing the clinical relevance of the findings (16).

However, certain limitations should be acknowledged. The follow-up period of four weeks was relatively short and may not fully capture the long-term process of periapical bone healing, which can extend over several months. As a result, the observed differences represent early healing trends rather than definitive treatment success. The sample size, although adequate to detect statistically significant differences, was modest and derived from a single regional setting, which may limit generalizability to broader populations. Furthermore, operator blinding was not feasible due to the nature of the intervention, introducing a potential risk of performance bias, although this was mitigated through standardized treatment procedures. The use of last observation carried forward for missing data may also influence outcome estimates, and future studies could incorporate sensitivity analyses to assess the robustness of findings under different assumptions (17).

Future research should focus on longer follow-up durations to evaluate sustained radiographic healing and long-term clinical success. Larger multicenter trials would enhance external validity and allow assessment of variability across different clinical settings and operator expertise levels. There is also a need for cost-effectiveness analyses to determine whether the incremental benefits of CBCT justify its use in routine clinical practice, particularly in resource-limited environments. Additionally, incorporating patient-reported outcome measures and quality-of-life assessments would provide a more comprehensive evaluation of treatment impact beyond radiographic and clinical parameters (18).

Overall, the findings indicate that cone-beam computed tomography enhances the effectiveness of retreatment in complex root canal cases by improving diagnostic accuracy and enabling more precise treatment planning. However, its optimal use lies in a targeted, case-based approach that balances diagnostic benefit with considerations of radiation exposure and clinical necessity (19).

CONCLUSION

Cone-beam computed tomography-guided retreatment of previously failed root canal cases resulted in significantly greater radiographic healing, lower pain intensity, and reduced clinical tenderness compared with retreatment planned using digital periapical radiographs, supporting its selective use in complex cases where enhanced three-dimensional visualization can meaningfully improve diagnostic precision and treatment outcomes while maintaining a balanced approach to radiation exposure and resource utilization.

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GRAPHICAL ABSTRACT