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Tomographic analysis of endodontic pathology derived from procedural errors in maxillary first molars: A cross-sectional study using CBCT

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Abstract
Context: In maxillary first molars, the complex root anatomy increases the risk of technical errors that can contribute to the development of periapical pathology. Cone-beam computed tomography (CBCT) allows for a three-dimensional evaluation of technical errors and periapical lesions.
Aims: To evaluate the presence of periapical pathology resulting from technical errors in endodontic treatments performed on maxillary first molars using CBCT.
Settings and Design: A retrospective cross-sectional observational study was conducted using CBCT scans obtained at a radiographic center in Quito, Ecuador, between 2020 and 2025.
Methods and Material: 748 endodontically treated maxillary first molars were evaluated. The images were analyzed to identify technical errors, including untreated canals, omission of the MV2 canal, underfilling, overfilling, instrument fracture, and root perforation.
Statistical analysis used: Descriptive statistics were used, including absolute frequencies and percentages. To determine the association between endodontic procedure errors and the presence of apical lesions, Pearson's chi-squared test was used, considering a significance level of $p < 0.05$. Additionally, the odds ratio (OR) with 95% confidence intervals (95% CI) was calculated to assess the strength of the association.
Results: Periapical lesions were present in 551 teeth (73.66%). The most frequent technical error was underfilling (42.4%). Root perforation showed the greatest risk of periapical lesions.
Conclusions: Periapical pathology was highly prevalent, with underfilling being the most frequent technical error. Root perforations were associated with a higher probability of periapical lesions, highlighting the importance of accurate anatomical identification and precise technical execution of endodontic treatment.

Keywords: Cone-Beam computed tomography, root canal therapy, periapical diseases, treatment failure

Introduction

Endodontic therapy is a clinical procedure for preserving tooth function by eliminating intraradicular infection and resolving periapical inflammation (Friedman, 2002) [7]. Despite advances in instrumentation and irrigation, primary treatments sometimes fail, as reflected in the persistence of apical periodontitis or the appearance of new lesions (Ng, Mann & Gulabivala, 2008; Wu, Dummer & Wesselink, 2006) [17, 29]. In such cases, non-surgical endodontic retreatment is the first alternative, since it allows for complementary disinfection and proper three-dimensional obturation (Siqueira & Rôças, 2008) [24].

The incorporation of Cone Beam Computed Tomography (CBCT) has considerably changed endodontic practice, as it overcomes the limitations of two-dimensional radiography without the interposition of anatomical structures or distortions that could be mistaken for endodontic lesions. Their three-dimensional diagnostic imaging facilitates the early detection of periapical lesions and anatomical variations, such as the mesiobuccal canal (MV2), whose prevalence is reported in 70–80% of maxillary first molars (Cleghorn, Christie & Dong, 2006 [2]; Studebaker *et al*., 2011). Omission of this canal is one of the most significant factors in treatment failure in maxillary molars.

The documented literature on procedural errors, including omitted canals, instrument fractures, perforations, underfillings, and overfillings, indicates that these errors are influenced by root morphology, calcifications, curvatures, or technical limitations (Vertucci, 1984 [27]; Neelakantan *et al*., 2010). Despite this, cases treated according to appropriate technical criteria may be related to factors such as persistent infection, cholesterol crystal deposits, or root fractures (Nair, 2006 [16]; Lin, Huang & Rosenberg, 2008).

In this context, CBCT is positioned as the best method for correlating the technical quality of treatment with the presence of periapical lesions, offering a more reliable analysis than conventional radiography (Estrela *et al*., 2008; Patel *et al*., 2020) [6, 19]. Therefore, the present study aims to evaluate, using CBCT, the association between endodontic procedure errors and the presence of periapical lesions in maxillary first molars, with the objective of providing clinical evidence to improve the diagnostic and therapeutic quality in endodontics.

Subjects and Methods

The study protocol was approved by the Institutional Ethics Committee under reference number CEUHE25-181.

Study Design: A retrospective, cross-sectional, observational study was conducted based on the analysis of images obtained using cone-beam computed tomography (CBCT) of endodontically treated maxillary first molars. The objective was to evaluate the association between endodontic procedural errors and the presence of periapical lesions.

CBCT scans of endodontically treated maxillary first molars were included. Inclusion criteria encompassed high-quality diagnostic studies that allowed for adequate visualization of the root canal system and the periapical region. Only acquisitions with a field of view (FOV) of 6×6 cm were considered. Images with severe artifacts, excessive noise, or extensive coronal fractures that prevented proper root evaluation were excluded.

The images were obtained using a NewTom GiANO HR cone-beam computed tomography (CBCT) scanner (Cefla, Italy), which utilizes electrically generated ionizing radiation produced in a high-frequency X-ray tube that transforms electrical energy into electromagnetic radiation, allowing the acquisition of three-dimensional images through differential tissue attenuation. A high-frequency generator with approximate parameters of 90 kV and a current range between 2 and 16 mA in 3D mode was used, employing pulsed emission to reduce the effective radiation dose. A field of view (FOV) of 6×6 cm was used, considered adequate for localized endodontic studies, as it provides high spatial resolution.

The sample size was calculated using the formula for finite populations, considering a population of 2,500 tomography scans, a 95% confidence level, a 3% margin of error, and an expected proportion of 50%, resulting in a final sample of 748 CBCT scans. The dependent variable was the presence or absence of periapical lesions, assessed using CBCT. Independent variables included endodontic procedural errors, such as untreated canals, omission of the secondary mesiobuccal canal (MV2), underfilling, overfilling, root perforation, and instrument fracture. These were defined using operational tomographic diagnostic criteria.

The DICOM images were analyzed using NNT Viewer software (NewTom, Italy). Each volume was previously reoriented in the axial, sagittal, and coronal planes, aligning the tooth's longitudinal axis with the reference planes to avoid distortions during evaluation. Visualization parameters were adjusted to optimize differentiation between tooth structures, obturation material, and periapical tissues.

The evaluation of endodontic procedural errors was performed using a standardized protocol based on three-dimensional observation in the axial, sagittal, and coronal planes, with the aim of ensuring accurate and relevant detection of each technical alteration. For diagnostic confirmation, concordance of findings in at least two observation planes was required.

Untreated canals were identified when an anatomically defined root canal was present without obturation material along any portion of its length. Evaluation was performed using sequential axial slices from the pulp chamber to the apex and corroborated in the sagittal and coronal planes to confirm canal continuity and rule out imaging artifacts.

Omission of the secondary mesiobuccal canal (MV2) was determined through sequential analysis. The axial plane was positioned at the level of the pulp chamber floor, and progressive apical displacement was performed using consecutive slices. The presence of two canals in the mesiobuccal root was identified, and the path of the additional canal was verified in the sagittal and coronal planes. Omission was defined as the absence of evidence of instrumentation or obturation material along its entire length.

Underfilling was defined as the obturation material ending more than 2 mm from the root apex, measured along the longitudinal axis of the canal in aligned sagittal or coronal sections. The measurement was taken in the plane that most accurately represented the actual canal length, minimizing errors due to angulation.

Overfilling was defined as the extension of the obturation material beyond the apical foramen, evidenced as radiopaque material extruded into the periapical tissues. This finding was evaluated in sagittal or coronal sections aligned with the canal axis and confirmed.

Statistical Methods

The data obtained were recorded in a collection matrix created in Microsoft Excel, where variables such as patient identification, the tooth evaluated, the root analyzed, and the evaluation by root thirds were recorded. Variables related to procedural errors were included, such as omitted MV2 canal, untreated canals, underfilling, overfilling, root perforation, and instrument fracture, as well as the presence or absence of periapical lesions. The variables were coded dichotomously (0 = absence, 1 = presence), which allowed for their proper organization and subsequent analysis. Statistical processing was performed using SPSS version 29.0 software.

A descriptive analysis of the qualitative variables was carried out by calculating absolute (n) and relative (%) frequencies in order to describe the distribution of procedural errors. Subsequently, a bivariate analysis was performed to evaluate the association between these errors and the presence of periapical lesions, using the chi-square test. In cases where expected frequencies were less than 5, exact tests were used.

The association was estimated by calculating the Odds Ratio (OR) with 95% confidence intervals to determine the probability of periapical lesions in relation to each type of error.

A statistical significance level of $p < 0.05$ was considered in all analyses.

Results

Cone-beam computed tomography (CBCT) scans of endodontically treated maxillary first molars were analyzed to evaluate the presence of procedural errors and their association with periapical pathology. The analysis included the distribution of the sample according to tooth type, the presence of apical lesions, the frequency of different endodontic procedural errors, their anatomical distribution, the presence of periapical lesions, and the statistical relationship between these factors.

The analysis identified several procedural errors in the evaluated maxillary first molars, as evidenced in the different tomographic slices. These findings illustrate the complexity of endodontic treatment in this tooth group and its potential impact on the presence and severity of periapical pathology.

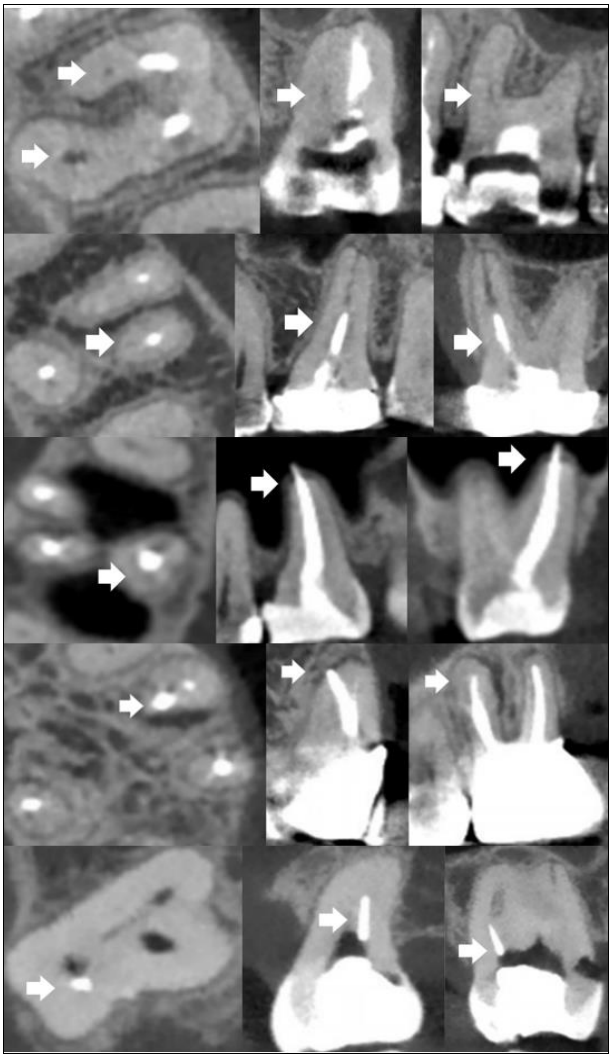

Fig 1: Procedural errors in first molars

Procedural errors in maxillary first molars evaluated by CBCT: omission of canals (including MV2), underfilling, overfilling, root perforations, and fractured instruments. Arrows indicate the affected areas.

Table 1 shows the distribution of maxillary first molars included in the study according to tooth type. Of the total sample analyzed, 377 teeth corresponded to the right maxillary first molar (16), representing 50.4%, while 371 teeth corresponded to the left maxillary first molar (26), equivalent to 49.6%.

This distribution shows a similar proportion between both sides of the maxilla, indicating adequate representation of the right and left maxillary first molars within the studied sample.

Table 1: Distribution of maxillary first molars included in the study according to tooth type

Tooth Type	n	%
26	371	49,60
16	377	50,40

Source: Author's own elaboration

Table 2 presents the distribution of endodontically treated maxillary first molars according to the presence of apical lesions. Of the total sample, 551 teeth (73.66%) presented apical lesions, while 197 teeth (26.34%) did not have apical lesions in the tomographic evaluation.

These results show a high frequency of apical lesions in endodontically treated maxillary first molars, highlighting the clinical relevance of tomographic analysis for the detection of periapical pathology and its possible association with procedural errors.

Table 2: Distribution of endodontically treated maxillary first molars according to the presence of apical lesion

Apical lesions	n	%
With injury	551	73,66
Without injury	197	26,34
Total	748	100

Source: Author's own elaboration

Table 3 shows the frequency of endodontic procedure errors identified in the evaluated maxillary first molars. A total of 809 errors were recorded, of which underfilling was the most frequent, with 343 (42.4%). The omitted MV2 canal occurred in 215 cases (26.58%), while untreated canals were identified in 153 cases (18.91%).

Underlying errors included overfilling, with 71 cases (8.78%), root perforation, with 24 (2.97%), and instrument fracture, which was the least frequent error, but may also be due to the difficulty in identifying files separated by tomography, with 3 cases (0.37%).

Table 3: Frequency of endodontic procedure errors identified in the evaluated maxillary first molars

Procedural errors	n	%
Untreated canals	153	18,91
Mv2 omitted	215	26,58
Underfilling	343	42,40
Overfilling	71	8,78
Instrument fracture	3	0,37
Perforation	24	2,97
Total	809	100

Source: Author's own elaboration

Table 4 presents endodontic procedure errors according to root and root third in the evaluated maxillary first molars. Omitted canals were most frequently identified in the mesiobuccal root, including 92 mesial canals and 215 mesiobuccal (MV2) canals, followed by the distal root with 50 cases and the palatal root with 11 cases.

Underfilling was observed mainly in the apical third of all roots, with 98 cases in the mesial root, 114 in the distal root, and 110 in the palatal root; in the middle third, 18, 17, and 17 cases were identified, respectively, while in the coronal third, 3 cases were observed, only in the palatal root.

Overfilling occurred exclusively in the apical third, with 21 cases in the mesial root, 24 in the distal root, and 17 in the palatal root. Root perforations were distributed across all three root thirds, most frequently in the apical third, with 3 cases recorded in the mesial root, 2 in the distal root, and 5 in the palatal root. Instrument fracture was identified only in the palatal root, with 3 cases located in the middle and apical thirds.

Table 4: Distribution of endodontic procedure errors according to root and root third in the first maxillary molars evaluated

Type of error	Root	Total n (%)	Coronal n (%)	Middle n (%)	Apical n (%)
Untreated canals	Mesial	92 (25,00%)	–	–	–
	Mesial MV2	215 (58,42%)	–	–	–
	Distal	50 (13,59%)	–	–	–
	Palatina	11 (2,99%)	–	–	–
Underfilling	Mesial	104 (30,32%)	0 (0,0%)	18 (34,62%)	98 (30,43%)
	Distal	122 (35,57%)	0 (0,0%)	17 (32,69%)	114 (35,40%)
	Palatina	117 (34,11%)	3 (100,0%)	17 (32,69%)	110 (34,16%)
Overfilling	Mesial	21 (33,87%)	0 (0,0%)	0 (0,0%)	21 (33,87%)
	Distal	24 (38,71%)	0 (0,0%)	0 (0,0%)	24 (38,71%)
	Palatina	17 (27,42%)	0 (0,0%)	0 (0,0%)	17 (27,42%)
Perforation	Mesial	10 (41,67%)	3 (50,0%)	4 (50,0%)	3 (30,0%)
	Distal	5 (20,83%)	1 (16,67%)	2 (25,0%)	2 (20,0%)
	Palatina	9 (37,50%)	2 (33,33%)	2 (25,0%)	5 (50,0%)
Instrument fracture	Mesial	0 (0,0%)	0 (0,0%)	0 (0,0%)	0 (0,0%)
	Distal	0 (0,0%)	0 (0,0%)	0 (0,0%)	0 (0,0%)
	Palatina	3 (100,0%)	0 (0,0%)	1 (100,0%)	2 (100,0%)

Source: Author's own elaboration

Table 5 shows the analysis of apical lesions in relation to different endodontic procedure errors was expressed as Odds Ratios (OR) and their 95% confidence intervals (95% CI). Untreated canals showed an OR of 1.02 (95% CI: 0.72–1.45), indicating a similar probability of apical lesion compared to cases without this error. The omitted MV2 canal showed an OR of 1.32 (95% CI: 0.97–1.81), demonstrating a higher probability of apical lesion, but without reaching statistical significance.

Underfilling showed an OR of 0.81 (95% CI: 0.61–1.07) and overfilling an OR of 0.72 (95% CI: 0.44–1.17), with no evidence of an increased risk of apical lesion. Instrument fracture registered an OR of 0.48 (95% CI: 0.04 – 5.27), with a wide confidence interval, and root perforation presented the highest OR value (2.37; 95% CI: 0.97 – 5.79), indicating a higher probability of apical injury in the presence of this error, although without statistical significance.

Table 5: Analysis of apical lesion in relation to the different endodontic procedure errors, expressed by Odds Ratio (OR)

Endodontic Procedure Error	OR	IC 95%	p
Untreated Canals	1,02	0,72 – 1,45	>0,05
Omitted MV2 Canal	1,32	0,97 – 1,81	
Underfilling	0,81	0,61 – 1,07	
Overfilling	0,72	0,44 – 1,17	
Instrument Fracture	0,48	0,04 – 5,27	
Root Perforation	2,37	0,97 – 5,79	

Source: Author's own elaboration

Discussion

The results of this study show a high frequency of apical lesions (73.66%), with a high prevalence of endodontic procedure errors, especially underfilling and omission of canals. These findings are consistent with previous research conducted in the Ecuadorian population using cone-beam computed tomography (CBCT).

Valverde Haro (2023) [26] reported that, in patients referred for endodontic retreatment, the most common technical errors included omission of canals, root transport, and poor obturation quality, which were associated with tooth anatomical characteristics and the presence of periapical reaction. These results support the usefulness of CBCT as a diagnostic tool for evaluating previously performed endodontic treatments.

Morales Torres (2020) [15], in analyzing 212 CBCT scans from Ecuadorian patients, determined that periapical lesions were the most frequent endodontic pathology (32.07%). While this percentage is lower than that observed in the present study, the difference may be attributed to variations in sample selection criteria.

Although the studies differ in their methodological approaches, Valverde Haro (2023) [26], focused on errors leading to retreatment, and Morales Torres (2020) [15], focused on the identification of pathologies using CBCT, both agree in highlighting the value of CBCT as a key diagnostic method for the accurate detection of endodontic alterations, technical errors, and their consequences in the Ecuadorian population.

In accordance with studies conducted in the Ecuadorian population, the results of this study also align with those reported in the international literature, which describes a high frequency of periapical lesions in endodontically treated teeth when using cone-beam computed tomography (CBCT). Several authors have indicated that the use of CBCT allows for a more precise evaluation of the periapical status, especially in multi-rooted teeth.

Patel *et al*. (2015) [20] highlight that CBCT increases the detection of periapical lesions, which could explain the high proportion of apical lesions observed in this study. This greater diagnostic capability is particularly relevant in maxillary molars, where anatomical complexity and the overlapping of structures can hinder traditional radiographic interpretation.

Regarding endodontic procedural errors, international research has reported results similar to those obtained in this study. Costa *et al*. (2019) [3] and Gaêta-Araujo *et al*. Jung *et al*. (2020) noted that omission of canals, especially the secondary mesiobuccal canal (MV2), is one of the most frequent errors in maxillary molars associated with periapical lesions. This finding coincides with the high frequency of omitted MV2 canals identified in the present study.

Likewise, Jung *et al*. (2017) [12] described that the quality of the obturation plays a fundamental role in the success of endodontic treatment, indicating that underfilling can favor the persistence of periapical infection. Although in this study underfilling did not show a statistically significant increase in the risk of apical lesion according to the Odds Ratio analysis, its high frequency suggests that it continues

to be a clinically relevant factor, which is consistent with what has been described in the international literature.

On the other hand, Gaêta-Araujo *et al*. (2020) [8] mention that root perforations are associated with more severe periapical lesions. This behavior is similar to that observed in the present study, where root perforation showed the highest odds ratio for the presence of apical lesions, although it did not reach statistical significance due to the limited number of cases.

The results of this research clearly correspond with international studies, reinforcing the evidence that endodontic procedural errors and the anatomical complexity of maxillary molars influence the presence and severity of periapical lesions.

The findings of this study allow us to understand the relationship between endodontic procedural errors and the presence of periapical lesions in maxillary first molars that have undergone endodontic treatment. The high proportion of apical lesions observed clarifies that the treatment outcome does not depend on a single factor, but rather on a combination of technical, anatomical, and diagnostic aspects.

Odds ratio analysis revealed that certain high-frequency errors, such as underfilling and omission of the MV2 canal, did not show a statistically significant association with the presence of apical lesions. However, their recurrence in the sample suggests that these errors have clinical relevance, and the statistical significance should be interpreted in conjunction with the clinical context.

In contrast, less common errors, such as root perforation, presented higher risk values, indicating a greater impact on periapical tissues when they occur. This result suggests that the severity of the error may be more decisive than its frequency, since some iatrogenic events can significantly compromise the tooth's prognosis.

Conclusions

This study revealed a high frequency of periapical lesions, confirming that periapical pathology remains a common finding when evaluated using cone-beam computed tomography (CBCT). These results highlight the importance of employing three-dimensional diagnostic methods for a more accurate assessment of the periapical status.

A high prevalence of endodontic procedural errors was identified, with underfilling and omission of canals, particularly the secondary mesiobuccal canal (MV2), being the most frequent errors. This reflects the technical difficulties associated with the treatment of maxillary first molars and underscores the need for adequate anatomical knowledge and correct execution of endodontic treatment.

Statistical analysis showed that, although some procedural errors did not present a statistically significant association with the presence of periapical lesions, their high frequency in the sample indicates that they remain clinically relevant. On the other hand, less frequent errors, such as root perforation, showed higher risk values for the presence of periapical lesions, indicating that the severity of the error may have a more decisive influence than its frequency of occurrence as assessed by the CBCTPA index. This suggests that more extensive lesions are usually related to more complex technical failures.

The errors predominantly occurring in the mesiobuccal root and the apical third confirm that these anatomical areas are a constant clinical challenge and remain critical for the success of endodontic treatment. In this context, CBCT is consolidated as a fundamental diagnostic tool for the accurate identification of technical errors and the evaluation of the extent of periapical lesions.

Finally, as this was a retrospective study, it was not possible to determine the exact time when the endodontic treatment was performed, establish whether the periapical lesion was present before the procedure or developed subsequently, or evaluate its clinical evolution over time. Despite these limitations, the results provide relevant evidence on the relationship between endodontic procedural errors and periapical pathology in maxillary first molars, highlighting the importance of proper planning, continuing education, and the rational use of CBCT to improve the prognosis of endodontic treatment.

Key Messages

This CBCT-based study demonstrated that technical errors in endodontically treated maxillary first molars are significantly associated with the presence of periapical pathology. Underfilling was the most frequent error, highlighting the importance of accurate working length determination and proper obturation quality.

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