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ORIGINAL ARTICLE

Accuracy of Digital Radiography and Cone Beam Computed Tomography in Assessing Filling Material Extrusion Using Micro-Computed Tomography as Gold Standard: A Study in Human Cadavers

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ABSTRACT

Objective: This study compared the accuracy of digital periapical radiography (DPR) and cone beam computed tomography (CBCT) in detecting extruded filling material, using a human cadaver model. Micro-computed tomography (Micro-CT) served as the gold standard.

Methods: A total of 27 single-rooted teeth embedded in cadaveric mandibular segments, obtained from a prior retreatment study, were included: 25 with confirmed apical extrusion of filling material on micro-CT and 2 without extrusion serving as negative controls. The segments were imaged using both DPR and CBCT. Two calibrated endodontists independently assessed the images for visible extrusion; discrepancies were resolved by a third evaluator.

Results: Although DPR demonstrated lower overall sensitivity than CBCT, both modalities showed identical specificity (100%). Diagnostic accuracy was 70% for DPR and 74% for CBCT, without statistically significant difference between them ($P > .05$). Moreover, the volume of extruded filling material was not a significant predictor of detection accuracy for either DPR ($P > .05$) or CBCT ($P > .05$).

Conclusion: In conclusion, both DPR and CBCT demonstrated low accuracy in detecting filling material extrusion, with no significant difference between them. The occurrence of false-negative results may compromise the reliable assessment of extruded filling materials. In cases of true extrusion, approximately one-third would go undetected by both methods.

Keywords: Apical extrusion, cone beam computed tomography, digital periapical radiography, endodontic retreatment, image diagnosis, microtomography

HIGHLIGHTS

- Both DPR and CBCT showed low diagnostic accuracy in detecting extruded filling materials.
- CBCT had slightly higher accuracy (74%) than DPR (70%), but the difference was not statistically significant.
- Both imaging methods achieved 100% specificity, reliably identifying absence of extrusion.

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INTRODUCTION

Root canal retreatment is indicated when the initial endodontic therapy fails. Its primary objective is to reestablish periradicular health by removing the previous filling material, enabling proper reshaping, cleaning, disinfection, and subsequent obturation of the canal.[1-3] A major concern during retreatment is the apical extrusion of debris, which may contain dentin particles, microorganisms, necrotic tissue remnants, and filling materials.[4,5] Such extrusion can cause postoperative pain, flare-ups, and may compromise the long-term healing of apical periodontitis.[6] Furthermore, extruded materials have been associated with foreign body reactions.[7,8]

Filling material extrusion is frequently observed, regardless of the retreatment protocol.[9-11] In ex vivo studies, the most common method for evaluating this phenomenon involves weighing the extruded material using extracted teeth.[12-14] However, this approach may introduce bias, as it does not accurately replicate the anatomical and biological resistance of periradicular tissues.[15] More recent studies have employed micro-computed tomography (micro-CT) to quantify the volume of extruded filling material with high accuracy and three-dimensional resolution,[9,16,17] including 1 study using a human cadaver model.[9] A key advantage of this model is the presence of the periodontal ligament and surrounding bone, which offers natural resistance to the filling material extrusion.[9]

Despite its precision, micro-CT remains limited to research settings and is not applicable in clinical practice. In contrast, digital periapical radiography (DPR) and cone beam computed tomography (CBCT) are commonly used in endodontic practice; however, their ability to detect extruded filling material has not been thoroughly validated. Therefore, this study aimed to compare DPR and CBCT in detecting extruded filling material, using micro-CT as the reference standard in teeth embedded in cadaveric mandibular segments.

MATERIALS AND METHODS

This cross-sectional observational study included 17 cadaveric mandibular segments containing premolars and canines previously used in a related study. Ethical committee approval was received from the Ethics Committee of Estácio de Sá University (Approval no: 1.696.413, Date: 25/08/2016).[9] All bone blocks were scanned using micro-CT (SkyScan 1273.v2; Bruker micro-CT, Kontich, Belgium) at 70 kV and 114 mA, with a pixel size of 14 µm, a full 360° rotation around the vertical axis, a 0.5° rotation step, and 2 averaged frames, using a 1.0-mm-thick aluminum filter, and teeth were selected according to the inclusion criteria established in the prior study: absence of extensive restorations or caries, cracks or fractures, internal or external root resorption; presence of a mature apex; and a single root canal. When not in use, specimens were stored in 10% formaldehyde.

The teeth underwent endodontic treatment using gutta-percha and AH Plus Jet as sealer (Dentsply Sirona, Charlotte, NC, USA) followed by retreatment, and the extrusion of filling material was detected and volumetrically quantified (mm^3) using micro-CT, as previously described.[9] Specimens were subsequently radiographed using DPR and scanned with CBCT. A total of 27 single-rooted teeth were included: 25 with confirmed apical extrusion of filling material on micro-CT and 2 without extrusion serving as negative controls.

Digital Periapical Radiography

Digital periapical radiographs were acquired using a NanoPix digital sensor (MKLife, Porto Alegre, RS, Brazil) and a Spectro 70X Seletronic X-ray unit (Dabi Atlante Ltda., Ribeirão Preto, SP, Brazil), operated at 70 kVp, 8 mA, with an exposure time of 0.35 seconds. To ensure reproducibility and parallel alignment of the X-ray beam, the sensor was stabilized on a workbench using non-permanent adhesive, maintaining a fixed 18 cm distance between each sample and the X-ray.

Cone Beam Computed Tomography

Cone beam computed tomography scans were obtained using a Morita X800 unit (J. Morita, Tokyo, Japan) with the following parameters: 100 kVp, 3.0 mA, 9.4-second scan time, a 40 × 40 mm field of view, and a voxel size of 0.125 mm. Specimens were secured in transparent plastic containers and positioned on the platform to ensure stability during image acquisition.

Image Analysis

Digital periapical radiographs were analyzed using NanoPix software (MKLife, Porto Alegre, RS, Brazil). The analyses of CBCT scans were performed dynamically using iDixel software (i-Dixel 3D; J. Morita, Tokyo, Japan), employing all reformatted multiplanar reconstructions (axial, coronal, and sagittal planes) aligned truly parallel and perpendicular to the long axis of the tooth under examination. Examiners were allowed to use image enhancement tools, including zoom, brightness, and contrast adjustments, at their discretion to optimize image interpretation. The axial plane was assessed first, serving as the initial reference for analysis. In this view, a guideline was placed centrally within the root canal, extending from the most cervical region to the apex of the root. Following the axial evaluation, the coronal plane was examined, and finally, the sagittal plane, with all assessments conducted along the full length of the tooth. Two board-certified endodontists independently evaluated each dataset to determine the presence or absence of apical extrusion of filling material (Fig. 1).

To minimize potential bias, each imaging modality was evaluated on different days, with a 1-week interval between assessments. In cases of disagreement, a third experienced endodontist was consulted. Intra- and inter-examiner agreement were assessed using the kappa test and ranked as excellent ($\kappa > 0.80$).

Statistical Analysis

Statistical analyses were performed using SPSS software (version 21.0; IBM Corp, Armonk, NY, USA). Sensitivity, specificity, positive predictive value, and negative predictive value were calculated using micro-CT as the reference standard. Receiver-operating characteristic (ROC) curve analysis was used to assess the diagnostic accuracy of DPR and CBCT in detecting extruded filling material. Differences between the 2 imaging modalities were evaluated using the chi-square test. Logistic regression analysis was conducted to assess whether the volume of extruded filling material, as determined by micro-CT, was associated with its detection by DPR or CBCT. A significance level of $\alpha = 0.05$ was adopted for all tests.

RESULTS

Overall, DPR demonstrated lower sensitivity than CBCT, as illustrated by the ROC curve (Fig. 2), although both methods achieved 100% specificity. The extrusion detection accuracy rates were 70% for DPR and 74% for CBCT. Despite the lower rate of correct diagnoses with

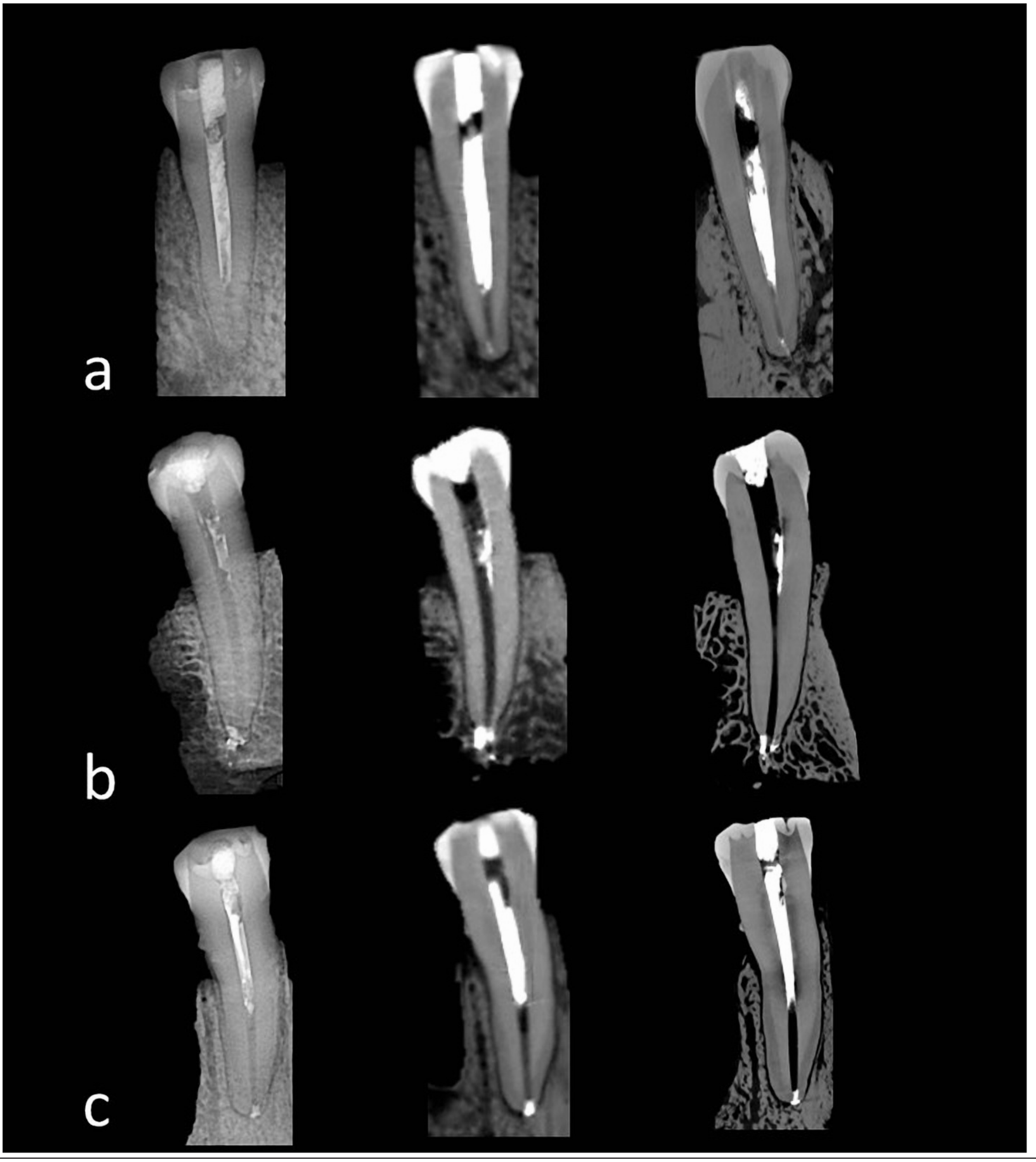

Figure 1. Comparison of imaging modalities applied to the same sample. From left to right: digital periapical radiography (DPR), cone beam computed tomography (CBCT), and micro-computed tomography (micro-CT). (a) First right mandibular premolar: absence of filling material extrusion in DPR and CBCT, but extrusion visible on micro-CT. (b) Second right mandibular premolar: extrusion of filling material visible in all imaging modalities. (c) First right mandibular premolar: extrusion of filling material visible in all imaging modalities.

DPR, the difference between the 2 modalities was not statistically significant ($P > .05$) (Table 1).

Logistic regression analysis revealed that the volume of extruded filling material, as quantified by micro-CT (mean: 0.264 ± 0.394 mm^3; median: 0.07 mm^3; range: 0.00-1.34 mm^3), was not a significant predictor of extrusion detection for either imaging modality. For DPR, the intercept was 0.174 (standard error=0.560, $P > .05$), with an odds ratio of 1.19 (95% CI: 0.397-3.57). The estimate for extruded volume was −7.503 (standard error=4.845, $P > .05$), corresponding to an odds ratio of 5.52×10^{-4} (95% CI: 4.15×10^{-8} to 7.33). For CBCT, the intercept was −0.0270 (standard error=0.568, $P > .05$), with an odds ratio of 0.973 (95% CI: 0.320-2.96), and the volume estimate was −7.5999 (standard error=4.845, $P > .05$), yielding an odds ratio of 5.01×10^{-4} (95% CI: 1.76×10^{-8} to 14.24).

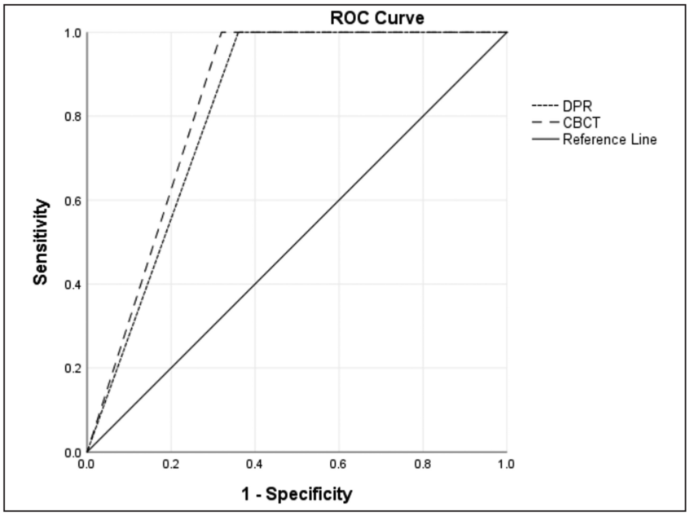

Figure 2. The receiver-operating characteristic (ROC) curve analysis for the tested methods. The larger the area under the ROC curve, the greater the accuracy.

DISCUSSION

This study evaluated the accuracy of DPR and CBCT in detecting extruded filling material after endodontic retreatment, using a human cadaver model. Micro-CT served as the gold standard, due to its superior resolution.[17] This is the first study to directly compare DPR and CBCT, 2 imaging modalities commonly employed in clinical practice, for this purpose. By utilizing a cadaveric model, this investigation offers valuable insights into the limitations and advantages of both techniques.

DPR and CBCT showed low accuracy in detecting extruded filling material, underscoring the inherent limitations of imaging techniques commonly used in clinical practice. Both techniques exhibited low sensitivity, with CBCT (72%) performing slightly better than DPR (68%); however, this difference was not statistically significant. These frustrating results mean that, in a sample of 100 real extrusion cases, 28 (CBCT) or 32 (DPR) would be undetected. Such false-negative results may have important clinical implications, especially when the etiology of symptoms such as paresthesia, flare-ups, or postoperative pain is unclear. Failure to detect extruded filling material could lead to misinterpretation of treatment success and compromise long-term prognosis by allowing persistent periapical inflammation to go unrecognized.

A favorable, albeit expected, finding was that both imaging modalities demonstrated 100% specificity, indicating equivalent reliability in correctly identifying the absence of periapical extrusion. However, as this was a non-interventional study, only 2 negative control specimens were available. Although a larger number of true negatives would have improved the reliability and generalizability of specificity estimates, deliberately preparing canals without extrusion to increase negative controls would not reflect the true clinical frequency of extrusion.

A previous study compared micro-CT and CBCT images of filling material extrusion using agarose-filled microtubes to simulate periradicular tissues and reported no false-negative results.[17] However, that study used a small sample size (n = 13), which increases the risk of a type II error. Moreover, although agarose gel can simulate soft tissue consistency, it does not replicate the complexity of anatomical features found in real clinical scenarios. In contrast, the use of cadaveric mandibular segments, as in the present study, provides a more anatomically accurate model, including the presence of bone and periodontal ligament, which enhances the clinical relevance of the findings.[9]

It was not expected that DPR demonstrated diagnostic performance comparable to that of CBCT, given its known limitation related to the superimposition of anatomical structures, which can reduce its accuracy, particularly in complex regions such as the posterior mandible. In this study, digital radiography was employed, which minimizes processing errors and offers greater accuracy compared to conventional periapical films.[18,19] Despite the similar performance of DPR and CBCT, it is essential to emphasize that CBCT remains crucial for detailed mapping of the affected region and for treatment planning in cases of more extensive extrusion, particularly when associated with symptoms and requiring surgical intervention.

The volume of extruded filling material was not a significant predictor of detectability. This finding suggests that other factors, such as the radiodensity of the material, may also influence the accuracy of extrusion detection.[20] AH Plus, the sealer used in this study, exhibits high radiopacity, exceeding that of most commercially available sealers.[21] Radiopacity is crucial for differentiating filling material from surrounding anatomical structures.[22] Despite this, detection accuracy remained low, indicating that less radiopaque sealers may be even more challenging to identify when extruded.

A limitation of this study is that the analysis was restricted to a single type of sealer with high radiopacity and to a specific tooth type. Further research is needed to test other sealers and establish the minimum volume of extruded material that can be reliably detected by DPR or CBCT. A previous study reported that small volumes of extruded material may be difficult to detect,[23] which could lead to an underestimation of periapical inflammatory reactions, potentially contributing to persistent pain or even treatment failure due to irritation of adjacent tissues.[3,9] Additionally, future studies should include teeth from other anatomical regions, such as molars or maxillary teeth, to assess whether increased cortical bone volume and anatomical complexity, like the maxillary sinus, could impact detection rates.

Radiographic imaging is essential for endodontic diagnosis and treatment planning, yet its limitations must be acknowledged. Although

Table 1. Frequency of Extrusion and Accuracy According to Imaging Methods

Imaging method	Frequency	Sensitivity (%)	Specificity (%)	PPV (%)	NPV (%)	LR+	LR–	Accuracy (%)
DPR	17	68	100	100	20	—	0.32	70
CBCT	18	72	100	100	22	—	0.28	74

LR–, negative likelihood ratio; LR+, positive likelihood ratio; NPV, negative predictive value; PPV, positive predictive value.

DPR and CBCT are routinely used, both methods failed to detect all cases with filling material extrusion. A similar limitation exists in diagnosing vertical root fractures, where even CBCT may miss fractures unless they are well defined or surrounded by sufficient contrast. In such cases, definitive diagnosis often requires direct visualization during surgery or extraction.[24] These findings underscore the importance of integrating radiographic data with clinical signs, symptoms, and complementary tools to enhance diagnostic reliability.

CONCLUSION

Both DPR and CBCT demonstrated low accuracy in detecting filling material extrusion, with no significant difference between them. The occurrence of false-negative results may compromise the reliable assessment of extruded filling materials. In cases of true extrusion, approximately one-third would go undetected by both methods.

Disclosures

Data Availability Statement: The data that support the findings of this study are available on request from the corresponding author.

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