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DEEP LEARNING–BASED DETECTION OF VERTICAL ROOT FRACTURES USING CONE-BEAM COMPUTED TOMOGRAPHY IN ENDODONTICALLY TREATED TEETH

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ABSTRACT
Vertical root fracture is another complication that is among the most challenging in endodontically treated teeth and mostly causes tooth extraction when diagnosed late. The traditional radiographic interpretation of cone-beam computed tomography has a high level of dependence on the experience of clinicians, and can be influenced by root filling material artifacts. The recent developments of artificial intelligence with the focus on deep learning have shown that it can be used to enhance the level of diagnostic accuracy in dental images. The present study examines the work of a deep learning-based model to detect vertical root fractures by analyzing cone-beam computed tomography images of endodontically treated teeth. An annotated dataset of cases was provided by the training and validation of a convolutional neural network architecture on clinical cases. The diagnostic performance was contrasted with those of experienced endodontists on the sensitivity, specificity, accuracy, and area under the curve. The findings indicated that the deep learning model was more diagnostic and had similar or better accuracy as compared to human examiners. The results indicate the clinical capability of artificial intelligence-aided diagnostic tools in the improvement of early vertical root fractures detection and clinical decision-making in endodontic practice.

Keywords:
Artificial intelligence, Deep learning, Vertical root fracture, Cone-beam computed tomography, Endodontics, Diagnostic accuracy

INTRODUCTION
Vertical root fracture is a major failure mode in an endodontically treated tooth and this is a major problem in the clinical practice as it is exceptionally difficult to diagnose. It is important to detect it early and correctly in order to avoid unnecessary retreatment and to identify the proper management approaches. Two dimensional traditional periapical radiography has poor capability of identifying fine fracture lines because it is two-dimensional. Cone-beam computed tomography has enhanced visualization of the diagnosis by offering a three-dimensional image, but interpretation of the image has been subjective and prone to beam-hardening artifacts due to obturation materials (Patel et al., 2019). Artificial intelligence has come up as a game changer in the field of dentistry, especially in diagnostic imaging. The Role of Artificial Intelligence in Endodontics: Advancements, Applications, and Future Prospects provides the information that artificial intelligence systems can be used to improve the diagnostic accuracy, treatment planning, and prognosis in the field of endodontics (Singh, 2022). Convolutional neural networks are deep learning models that have shown better results in pattern recognition challenges in medical imaging (LeCun et al., 2015). The applications of AI in endodontics have been broadened to detection of periapical lesions, identification of root canal morphology, working length, and fracture diagnosis (Orhan et al., 2020; Zhang et al., 2021). Nonetheless, there is a dearth of data about the accuracy of deep learning model in the identification of vertical root fractures in endodontically treated teeth with the use of cone-beam computed tomography. This research is expected to assess the diagnostic accuracy of a deep learning-based system and compare it with seasoned endodontists.

BACKGROUND OF THE STUDY
vertical root fracture Vertical root fracture refers to longitudinal fractures extending along the root and are usually caused by excessive mechanical stress during obturation or upon placement of the post (Tamse, 2006). Nonspecific points of observation can be isolated periodontal pockets, sinus tracts, or percussion tenderness but

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these are not clinical manifestations. Cone-beam computed tomography has a better spatial resolution and multiplanar visualization and thus better fracture detection (Patel et al., 2019). Although these benefits exist, CBCT images can give artifacts that can either resemble or block fracture lines, creating a false-positive or false-negative interpretation (Bechara et al., 2013). Complex imaging patterns that are beyond the human perception constraints can be analyzed by artificial intelligence and especially deep convolutional neural networks (Esteva et al., 2017). Singh (2022) highlighted the fact that AI-based systems in endodontics can help clinicians to decrease diagnostic diversity and enhance consistency. A combination of AI and CBCT imaging could thus be a more objective diagnostic tool in the identification of vertical root fractures.

LITERATURE REVIEW

Dental diagnostics have been rapidly growing in the field of artificial intelligence. Convolutional neural networks, which are deep learning architectures, have been very effective at image classification (LeCun et al., 2015). CNN-based models have been used to identify caries, periodontal bone loss and periapical lesions with high accuracy in dentistry (Lee et al., 2018; Orhan et al., 2020). Regarding endodontics, Singh (2022) noted that AI technologies help improve the reliability of diagnostics and lessen the reliance of operators. CBCT-trained deep learning models have demonstrated potential in detecting apical pathologies and morphologic variations of roots (Zhang et al., 2021). The process of vertical root fracture identification is still complicated with fine radiography images and filling material artifacts. Patel et al. (2019) emphasized that CBCT is a better method of detection than the periapical radiography, but the interpretation still relies on the experience of the clinician. According to Bechara et al. (2013), CBCT imaging has a great negative impact on diagnostic accuracy due to the existence of metallic artifacts. Recent works have tested fracture detection with AI. The authors of the study by Fukuda et al. (2019) created a CNN model to identify root fractures and indicated a higher sensitivity than general dentists. The same was noted by Orhan et al. (2020), who exhibited high diagnostic performance with the use of deep learning algorithms..

Study	Application	Imaging Modality	Reported Accuracy
Lee et al. (2018)	Caries detection	Periapical radiographs	89%
Orhan et al. (2020)	Periapical lesion detection	CBCT	92%
Zhang et al. (2021)	Root morphology analysis	CBCT	94%
Fukuda et al. (2019)	Root fracture detection	CBCT	90%

Table 1 summarizes selected studies on AI applications in endodontic imaging.

METHODOLOGY

It was a retrospective diagnostic accuracy study performed based on CBCT scans accumulated over the period of 2022-2025 on patients who have received endodontic treatment at a university dental clinic. Data collection was done with ethical approval. The initial screening of 420 CBCT volumes and 300 scans were eligible with the inclusion criteria of complete obturated single-rooted teeth and the presence of the clinical diagnosis. Vertical root fracture presence ground truth was defined by the presence of the surgical confirmation or extraction findings. Two experienced endodontists also interpreted the scans in order to confirm the fracture status. Consensus discussion was used to resolve the disagreements. The standardization of the voxel size and contrast normalization of CBCT images were preprocessed. The suspected root area was manually segmented into areas of areas of interest. Rotation, flipping and contrast adjusting of data were used to augment data with variability. A Python and Tensorflow convolutional neural network in the ResNet-50 architecture were used. The data was separated into training, validation and test data sets at 70, 15 and 15 percent. The model training was done in 100 epochs with the batch size of 16. The loss function was the Adam optimizer and binary cross-entropy. The performance metrics here were sensitivity, specificity, accuracy, and precision as well as area under the receiver operating characteristic curve. Three endodontists board certified compared their diagnostic results of AI model with that of three board-certified endodontists performing independent assessments in the same test data set.

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Dataset	Number of Cases	Fracture Positive	Fracture Negative
Training	210	105	105
Validation	45	22	23
Testing	45	23	22

Table 2 presents the dataset distribution.

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RESULTS

The deep learning model achieved an overall accuracy of 93.3% on the test dataset. Sensitivity was 91.3%, specificity 95.4%, and area under the curve 0.96. In comparison, the mean diagnostic accuracy of the three endodontists was 87.5%.

Table 3 compares performance metrics between AI and clinicians.

Metric	Deep Learning Model	Endodontists (Mean)
Accuracy	93.3%	87.5%
Sensitivity	91.3%	84.8%
Specificity	95.4%	90.2%
AUC	0.96	0.89

There was a significant difference in the accuracy of diagnosis in favor of the AI model ($p < 0.05$) statistically. The interrater reliability of clinicians showed moderate values of kappa, and AI results were also consistent between repeated testing. Beam-hardening artifacts mostly contributed to false positives and incomplete fracture lines were mostly considered false negatives. The deep learning model showed to be better able to detect subtle cases of fractures than the human examiners.

DISCUSSION

The research results provided by this paper can support the fact that artificial intelligence can help achieve a high level of diagnostic accuracy in endodontic imaging. In line with Singh (2022), AI-driven systems show the ability to lower the variability of the operators and enhance clinical efficiency. The high performance of the deep learning model corresponds with previous research by Orhan et al. (2020) and Fukuda et al. (2019) who had high sensitivity in detecting fractures. CBCT interpretation is still prone to artifact and subjective biasness as Patel et al. (2019) have already mentioned. The current findings showed that convolutional neural networks have the potential to learn to distinguish fracture patterns with imaging artifacts. Nonetheless, to be incorporated in clinical workflows, it is necessary to verify it in multicenter databases and real-time test settings. The weaknesses consist of the retrospective design and the demographics of the sample. Future studies ought to consider bigger data sets, implementing them in conjunction with cloud-based diagnostics, and utilizing hybrid AI-physician decision support systems.

CONCLUSION

Deep learning constructions identify vertical root fractures with a cone-beam computed tomography have a high diagnostic accuracy and consistency with experienced endodontists. The artificial intelligence model was found to have better sensitivity and specificity, which explains why it can be a useful adjunctive tool in endodontic diagnosis. AI-driven systems could be used to optimize treatment planning and patient outcomes by making them less subjective and more able to perform early fracture diagnoses. Artificial intelligence integration into the endodontic imaging processes is a very important step in the digital dentistry sphere. AI-assisted diagnostic systems may also prove to be effective decision-support systems with additional verification and bigger multicenter studies, making them more effective and accurate in clinical practice.

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