Review Article

Artificial intelligence in the diagnosis of vertical root fractures: a comprehensive review

[1]Palak Batra, [2]Bonny Paul, [3]Shivkumar Mantri, [4]Kavita Dube, [5]Maitri Sharma

[1,5]Postgraduate student, [2,4]Professor, [3]Professor and Head of the Department, Department of Conservative Dentistry and Endodontics, Hitkarini Dental College and Hospital, Jabalpur, Madhya Pradesh, India

ABSTRACT:
Aim: This comprehensive review is aimed at evaluating the diagnostic and prognostic accuracy of artificial intelligence in detecting vertical root fracture. **Materials and methods:** PubMed, Web of Science, and Google Scholar were searched to collect the most relevant articles using terms, such as AI, endodontics, vertical root fracture and dentistry. This review included 30 papers related to AI in diagnosing vertical root fracture. **Results:** The potential application of several AI models in identifying vertical root fracture was highlighted by the evaluation of thirty-one studies. It was discovered that up to 95.7% of vertical root fractures could be detected. **Conclusion:** The analysis of the research showed that the application of AI is promising and may support customised endodontic treatment. It would assist the dentist in identifying vertical root fractures early and accurately, which would facilitate appropriate treatment.
Keywords: Artificial intelligence, Vertical root fracture, Endodontics

Corresponding Author: Palak Batra, Postgraduate student, Department of Conservative Dentistry and Endodontics, Hitkarini Dental College and Hospital, Jabalpur, Madhya Pradesh, India

INTRODUCTION
A complete or incomplete longitudinal fracture that usually starts at any position along the root and typically runs in a buccolingual direction is what defines a vertical root fracture (VRF).[1] It is anticipated that 3.7- 30.8% of teeth that have received endodontic treatment may experience vertical root fractures; mandibular premolars and molars are the most frequently affected teeth.

A precise diagnosis is necessary for the treatment of vertical root fractures (VRF), which can involve extraction or partial root resection. [2] Transillumination [3] , projection radiography [4], bite testing [5], periodontal probing [6], sinus tract detection [6], and direct visual inspection [5] are traditional techniques for identifying vertical root fractures. [7] Cone-beam computed tomography (CBCT) has grown in significance among the different diagnostic techniques for identifying vertical root fractures due to its three-dimensional (3D) imaging capabilities and submillimeter spatial resolution. [8] The accuracy of

artificial intelligence applied over CBCT is even higher for diagnosing vertical root fracture.

MATERIALS AND METHODS
PubMed, Web of Science, and Google Scholar were searched to collect the most relevant articles using terms, such as AI, endodontics, vertical root fracture and dentistry. This review includes30 papers related to AI in diagnosing vertical root fracture.

RESULTS AND DISCUSSION
The potential application of several AI models in identifying vertical root fracture was highlighted by the evaluation of thirty-one studies. It was discovered that up to 95.7% of vertical root fractures could be detected.

ARTIFICIAL INTELLIGENCE IN DENTISTRY
By improving many facets of dental care and making treatments more accurate and efficient, artificial intelligence is significantly contributing to the revolution of dentistry and the transformation of

conventional dental practices. AI-powered virtual dental assistants perform tasks with a high level of precision and require less staff, ensuring accuracy and efficiency in dental facilities. AI-powered systems may examine intraoral images, radiographs, and dental records to find anomalies, support treatment choices, and offer tailored advice.

Conventional machine learning methods have been surpassed by neural networks (NN), particularly when dealing with complicated input types like language or images. Artificial neural networks (ANN) and convolutional neural networks (CNN) are commonly the foundation of artificial intelligence. An artificial neural network (ANN) is a decision-making system that draws inspiration from the biological neural networks found in the brain. The layers of neurons in a typical ANN are fully linked. A number of hidden layers are used to transmit the input forward. The artificial neurons in the hidden layers can generate an output using an activation function after receiving a set of weighted inputs.[9]

Convolutional Neural Networks (CNNs) can effectively recognise and categorise dental structures, identify abnormalities like cavities, root fractures, and periodontal diseases, and help with precise segmentation of teeth and surrounding anatomical features, thereby improving image-based diagnosis.[10]

AI has found widespread use in the healthcare industry, transforming the way doctors diagnose, treat, and oversee patient care.

Artificial Intelligence in Diagnostics
It supports the detection and management of oral diseases by identifying and classifying suspicious mucosal changes indicative of premalignant or malignant conditions.[11]

AI-enabled applications allow clinicians or patients to upload lesion images, compare them with extensive global datasets, and receive rapid, expert-level assessments.[12]

Artificial Intelligence in Patient Management
AI can help with scheduling clinic consultations for patients with dental issues, collecting the patient's full medical and dental history, managing funding, and providing the dentist with an appropriate evaluation and treatment plan.[13]

Artificial Intelligence in the Dental Education System
Clinical dentistry is essential for developing students' skills and ensuring high-quality patient care. Traditionally, preclinical training relied on conceptual learning and hands-on practice, but recent advancements have introduced artificial intelligence into dental education. AI-driven simulation systems recreate real clinical procedures in 3D, allowing students to practice repeatedly, refine techniques, and minimize the risk of iatrogenic errors before treating actual patients. This modern training approach is more effective, cost-efficient, and reliable.[14]

Artificial intelligence in endodontics
With its ability to improve clinical decision-making, increase patient care efficiency, and improve diagnostic accuracy, artificial intelligence (AI) has emerged as a key tool in endodontics. AI models, like as convolutional neural networks (CNNs), help identify periapical lesions, vertical root fractures, missing canals, and abnormalities in root morphology in periapical and CBCT images. This is one of the most significant applications in radiography interpretation. These devices assist in spotting minute radiographic alterations that medical professionals would miss.

In order to increase accuracy and lower the possibility of procedural errors, AI is also being used for automated working length assessment, root canal anatomy mapping, and real-time guidance during endodontic treatments. Machine learning algorithms can be used in treatment planning to evaluate risk factors, forecast the prognosis of root canal treated teeth, and assist in making decisions about extraction, surgery, or retreatment.[15]
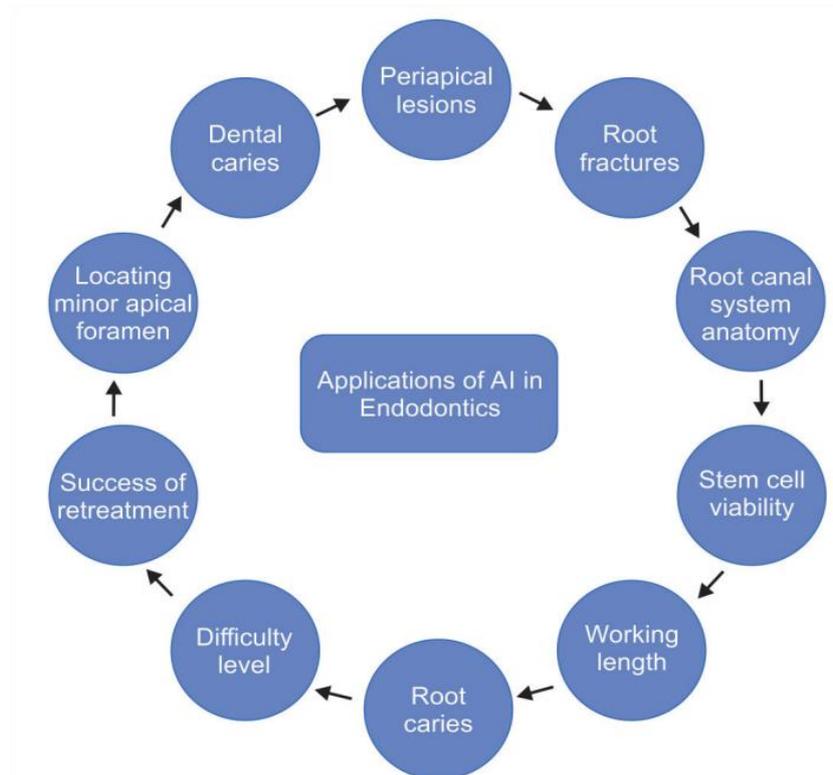
Figure 1- Applications of artificial intelligence in endodontics
(Courtsey: Ahmed ZH, Almuharib AM, Abdulkarim AA, et al. Artificial Intelligence and Its Application in Endodontics: A Review. J Contemp Dent Pract 2023;24(11):912–917)

ARTIFICIAL INTELLIGENCE IN DETECTING VERTICAL ROOT FRACTURE

VRF teeth may be misdiagnosed due to vague indications and symptoms.[1] Root fractures must be diagnosed as soon as possible because they can lead to gingival sulcus inflammation, periodontium destruction, and ultimately alveolar bone loss in nearly all teeth.[16]

Almost all VRF teeth are extracted or treated using hemisection or root separation techniques since they are among the hardest to properly treat. [16] On the other hand, early treatment that includes the removal of contaminated roots can lead to significantly longer survival durations for the remaining roots, with survival rates after five and ten years of 94% and 64%, respectively.[17]

Transitioning from conventional radiography to digital imaging and digital image enhancement has been explored to improve the diagnostic detection capabilities of radiographic techniques.[18] A dentist is often faced with a diagnostic conundrum due to the clinical presentation and the low sensitivity of diagnostic imaging in identifying VRFs. [19]

To diagnose VRF, radiographic methods including periapical radiography were created. However, fracture lines are only apparent when the X-ray beam is parallel to the fracture plane or when root pieces are clearly separated, and 2-dimensional radiography pictures are limited due to the overlap of nearby structures.[20] Cone beam computed tomography (CBCT) has gained popularity in dentistry recently and may be utilised to diagnose VRF.[21] However, some studies claim that because fracture width changes, CBCT's diagnostic effectiveness is still unstable (sensitivity and specificity with 53–98% and 80–98%, respectively).[22] The majority of symptomatic fractures were found to have a width between 60 and 770 μm.[23] Currently available CBCT systems have voxel sizes ranging from 75 μm to 150 μm. when the fracture width is near the CBCT system's voxel size. The details on CBCT images grew hazy, making it difficult to diagnose fractures without a radiologist's expertise.[24]

The inability of conventional methods to accurately detect VRFs has prompted an invitation to investigate novel approaches for improving the diagnosis of VRFs.[25] The VRFs are detected by AI programs like ML, CNN(convolutional neural network), and PNN (probabilistic neural network).[19]

Recent studies evaluating the integration of artificial intelligence and digital imaging in dental diagnostics have demonstrated notable improvements in detection accuracy across various radiographic modalities.

Hassan et al.[26] (2009), compared the accuracy of CBCT and periapical radiographs in detecting vertical root fractures (VRFs) and evaluated the effect of root canal filling (RCF) on fracture detection. Eighty prepared teeth were divided into four groups, with fractures induced in groups A and B and RCF applied in groups A and C. Four observers assessed all images. CBCT showed higher sensitivity (79.4%) than PRs (37.1%), with specificities of 92.5% and

48

95%, respectively. RCF significantly reduced CBCT specificity but did not affect its overall accuracy, whereas RCF reduced both the sensitivity and overall accuracy of PRs. Overall, CBCT demonstrated superior accuracy (0.86) compared to PRs (0.66) for identifying VRFs.

Varshosaz et al.[27] (2010), reported accuracy of 91%, when applying software-based analysis to CBCT and periapical radiographs.

Metska et al.[28] (2012) achieved even higher diagnostic performance, with reporting an accuracy of 93%.Thirty-nine endodontically treated teeth suspected of vertical root fractures (VRFs) were evaluated using two CBCT systems (NewTom 3G and 3D Accuitomo 170).Overall, the 3D Accuitomo 170 provided superior accuracy and reproducibility for detecting VRFs, indicating that diagnostic performance varies by CBCT system.

Kositbowornchai et al.[18] in 2013 developed a Probabilistic Neural Network for VRF detection using digital radiography The artificial neural network is trained and tested using two hundred digital radiography-derived pictures (fifty sound and 150 vertical root fractures).The efficacy of the PNN-based model in detecting VRF in dental radiographs showed how AI may be used to tackle this difficult endodontic diagnosis problem.

Johari et al. [29]aimed to develop a probabilistic neural network (PNN) to diagnose VRFs in both intact and endodontically treated teeth using periapical and CBCT radiographs, while comparing the efficacy of these imaging methods. A total of 240 radiographs (120 VRF, 120 non-VRF; half endodontically treated, half intact) were divided into three training/testing groups. Daubechies 3 wavelet analysis and Gabor filters were used to extract image features for PNN training. In periapical radiographs, the network achieved a maximum accuracy of 70.0%, sensitivity of 97.78%, and specificity of 67.7%, whereas CBCT images yielded 96.6% accuracy, 93.3% sensitivity, and 100% specificity. These results indicate that the PNN is effective for diagnosing VRFs, with CBCT outperforming periapical imaging. Limitations include using only sound one-rooted premolars without restorations and not simulating adjacent anatomical structures, suggesting the need for further in vitro studies with full-skull and soft tissue simulation.

Fukuda et al. [10] in 2020 used convolutional neural network (CNN) for detecting vrf on panoramic radiography and reported a 75% sensitivity and a 93% positive predictive value in their detection, serving as a computer-aided diagnosis (CAD) tool for clinicians.However, because panoramic radiography uses two-dimensional imaging, CNNs are only able to extract a limited amount of information from the images, and their diagnostic efficiency is inadequate. Compared to panoramic radiography, CBCT may be able to provide far more detailed picture information on teeth because of its high-resolution, three-dimensional imaging.

Vicory et al. [30] in 2021 used machine learning for detecting microfracture on CBCT. Cone beam computed tomography (CBCT) has been used to identify microfractures, though with limited effectiveness. To improve detection, we developed an algorithm that integrates high-resolution (hr) CBCT scanning with advanced image processing and machine learning. Microfractures were artificially created in extracted human teeth (n=22), and both hr-CBCT and microCT images were collected, along with control samples (n=14). Using wavelet pyramid construction, phase images of the Fourier-transformed scans were produced and analyzed with a U-Net deep learning model capable of mapping the orientation and extent of cracks. This generated slice-wise probability maps showing potential microfractures. The ratio of high-probability voxels to total tooth volume was then assessed to estimate the likelihood of cracks. Fractured teeth consistently showed higher voxel ratios in both imaging methods. This framework introduces a new quantitative approach for assessing tooth structural damage. Future work will extend the model to full 3D volumes, enhance hr-CBCT feature extraction, and validate the system clinically. Early microfracture detection may allow better treatment planning and prolonged tooth survival.

Hu et al. [1] 2022 evaluated CBCT images of 276 teeth, equally divided between VRF and non-VRF cases, with diagnoses confirmed by two radiologists. Using manually and automatically selected regions of interest, three deep learning models—ResNet50, VGG19, and DenseNet169—were tested. ResNet50 achieved the best results in both groups, showing 97.8% accuracy in manual selection and 91.4% accuracy in auto-selection, outperforming the other models and even the radiologist. These findings suggest that ResNet50 is a highly effective tool for assisting in VRF detection.

CONCLUSION

The diagnosis of vertical root fractures has changed dramatically as a result of the application of AI in endodontics. This has been demonstrated by the application of CNN, ANN, and several machine learning models, which have improved clinical decision-making, enhanced treatment planning, and increased diagnostic precision. Vertical root fractures can occasionally be difficult for the human eye to notice, but AI can successfully evaluate radiographic features to detect them with greater accuracy. An early diagnosis improves prognosis and treatment options.

REFERENCES

1. Hu, Z., Cao, D., Hu, Y. et al. Diagnosis of in vivo vertical root fracture using deep learning on cone-beam CT images. BMC Oral Health 22, 382 (2022).
2. Khasnis SA, Kidiyoor KH, Patil AB, Kenganal SB. Vertical root fractures and their management. J Conserv Dent. 2014;17(2):103–10.
3. Bender IB, Freedland JB. Adult root fracture. J Am Dent Assoc 1983;107:413–9. 10.

4. Meister F, Lommel TJ, Gerstein H. Diagnosis and possible causes of vertical root fractures. Oral Surg Oral Med Oral Pathol1980;49:243–53.
5. Seo DG, Yi YA, Shin SJ, et al. Analysis of factors associated with cracked teeth. J Endod2012;38:288–92.
6. Testori T, Badino M, Castagnola M. Vertical root fractures in endodontically treated teeth: a clinical survey of 36 cases. J Endod1993;19:87–91.
7. Chang E, Lam E, Shah P, Azarpazhooh A. Cone-beam computed tomography for detecting vertical root fractures in endodontically treated teeth: a systematic review. J Endod. 2016 Feb;42(2):177–185. doi:10.1016/j.joen.2015.10.005
8. Ahmed, Zeeshan Heera et al. "Artificial Intelligence and Its Application in Endodontics: A Review." The journal of contemporary dental practice vol. 24,11 912-917. 1 Nov. 2023, doi:10.5005/jp-journals-10024-3593
9. Kavzoglu T. Determining optimum structure for artificial neural networks. Paper presented at: Proceedings of the 25th Annual Technical Conference and Exhibition of the Remote Sensing Society; 1999. Cardiff, UK.
10. Fukuda M, Inamoto K, Shibata N, Ariji Y, Yanashita Y, Kutsuna S, et al. Evaluation of an artificial intelligence system for detecting vertical root fracture on panoramic radiography. Oral Radiol. 2019;36(4):337–343. doi:10.1007/s11282-019-00409-x
11. Aboalshamat K.T. Perception and Utilization of Artificial Intelligence (AI) among Dental Professionals in Saudi Arabia. Open Dent. J. 2022;16 doi: 10.2174/18742106-v16-e2208110.
12. Butera A., Maiorani C., Gallo S., Pascadopoli M., Buono S., Scribante A. Dental Erosion Evaluation with Intact-Tooth Smartphone Application: Preliminary Clinical Results from September 2019 to March 2022. Sensors. 2022;22:5133. doi: 10.3390/s22145133.
13. Bryne E., Hean S., Evensen K., Bull V. More than just a dental practitioner: A realist evaluation of a dental anxiety service in Norway. Eur. J. Oral Sci. 2021;129:e12820. doi: 10.1111/eos.12820.
14. Gandedkar N.H., Wong M.T., Darendeliler M.A. Seminars in Orthodontics. Volume 27. WB Saunders; Philadelphia, PA, USA: 2021. Role of Virtual Reality (VR), Augmented Reality (AR) and Artificial Intelligence (AI) in tertiary education and research of orthodontics: An insight; pp. 69–77.
15. Ahmed ZH, Almuharib AM, Abdulkarim AA, et al. Artificial Intelligence and Its Application in Endodontics: A Review. J Contemp Dent Pract 2023;24(11):912–917.
16. Prithviraj D., Balla H., Vashisht R., Regish K., and Suresh P., An overview of management of root fractures, Kathmandu University Medical Journal. (2015) 12, no. 3, 222–230.
17. Karobari MI, Adil AH, Basheer SN, Murugesan S, Savadamoorthi KS, Mustafa M, et al. Evaluation of the diagnostic and prognostic accuracy of artificial intelligence in endodontic dentistry: a comprehensive review of literature. Sci World J. 2023;2023:7049360. doi:10.1155/2023/7049360.
18. Kositbowornchai S., Plermkamon S., and Tangkosol T., Performance of an artificial neural network for vertical root fracture detection: an ex vivo study, Dental traumatology. (2013) 29, no. 2, 151–155.
19. Nagendrababu V., Aminoshariae A., and Kulild J., Artificial intelligence in endodontics: current applications and future directions, Journal of Endodontics. (2021) 47, no. 9, 1352–1357.
20. Tsesis I, Kamburoğlu K, Katz A, Tamse A, Kaffe I, Kfir A. Comparison of digital with conventional radiography in detection of vertical root fractures in endodontically treated maxillary premolars: an ex vivo study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod. 2008;106(1):124–8.
21. Hassan B, Metska ME, Ozok AR, van der Stelt P, Wesselink PR. Detection of vertical root fractures in endodontically treated teeth by a cone beam computed tomography scan. J Endod. 2009;35(5):719–22.
22. Makeeva IM, Byakova SF, Novozhilova NE, Adzhieva EK, Golubeva GI, Grachev VI, et al. Detection of artificially induced vertical root fractures of different widths by cone beam computed tomography in vitro and in vivo. Int Endod J. 2016;49(10):980–9.
23. Chavda R, Mannocci F, Andiappan M, Patel S. Comparing the in vivo diagnostic accuracy of digital periapical radiography with cone-beam computed tomography for the detection of vertical root fracture. J Endod. 2014;40(10):1524–9.
24. Gao A, Cao D, Lin Z. Diagnosis of cracked teeth using cone-beam computed tomography: literature review and clinical experience. DentomaxillofacRadiol. 2021;50(5):20200407.
25. Talwar S., Utneja S., Nawal R. R., Kaushik A., Srivastava D., and Oberoy S. S., Role of cone-beam computed tomography in diagnosis of vertical root fractures: a systematic review and meta-analysis, Journal of Endodontics. (2016) 42, no. 1, 12–24.
26. Hassan B., Metska M. E., Ozok A. R., van der Stelt P., and Wesselink P. R., Detection of vertical root fractures in endodontically treated teeth by a cone beam computed tomography scan, Journal of Endodontics. (2009) 35, no. 5, 719–722.
27. Varshosaz M., Tavakoli M. A., Mostafavi M., and Baghban A. A., Comparison of conventional radiography with cone beam computed tomography for detection of vertical root fractures: an in vitro study, Journal of oral science. (2010) 52, no. 4, 593–597.
28. Metska M. E., Aartman I. H. A., Wesselink P. R., and Özok A. R., Detection of vertical root fractures _in vivo_ in endodontically treated teeth by cone-beam computed tomography scans, Journal of Endodontics. (2012) 38, no. 10, 1344–1347.
29. Johari M., Esmaeili F., Andalib A., Garjani S., and Saberkari H., Detection of vertical root fractures in intact and endodontically treated premolar teeth by designing a probabilistic neural network: an ex vivo study, Dentomaxillofacial Radiology. (2017) 46, no. 2,
30. Vicory J., Vicory J., Chandradevan R., Hernandez-Cerdan P., Huang W. A., Fox D., Qdais L. A., McCormick M., Mol A., Walter R., Marron J. S., and Geha H., Dental microfracture detection using wavelet features and machine learning, Medical imaging 2021: image processing 2021, 2021, 484–492.